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1. PREFACE

PREVIOUS recommendations of the Commission have been given in Recommendations of the International Commission on Radiological Protection—adopted 1958 (ICRP Publication 1), and in the " Report on decisions at the 1959 meeting of the ICRP ", published in 1959 and reprinted in a number of scientific journals. In addition, both of the above publications have been reprinted with the Report of Committee II on Permissible Dose for Internal Radiation (ICRP Publication 2), 1959, and with the Report of Committee III on Protection Against X-rays up to Energies of 3 MeV and Beta- and Gamma-Rays from Sealed Sources (ICRP Publication 3), 1960.

Subject to the amendments and comments given in Part 3 of this report, all recommendations made in the above publications are still valid. Although the 1958 Recommendations have been amended both in 1959 and 1962, the Commission has decided not to publish at this time a new revised version of its general recommendations. This is partly because there has as yet been no change in the basic philosophy calling for radical revision of the old text, and partly because it is felt that it would be confusing to have two separate texts with essentially the same content but with somewhat different wordings.

For the reader's convenience, however, the revised text of Chapter C on Maximum Permissible Doses (paragraphs 45–70 of the 1958 Recommendations), as amended in 1959 and 1962, has been included in Part 4 of this report. Chapters A, B, and D of the 1958 Recommendations are also reproduced in Part 4, showing the relevant amendments. Part 4 thus contains all of the Commission's general recommendations, as amended to 1962.

2. ORGANIZATION

THE International Commission on Radiological Protection originated in the Second International Congress of Radiology in 1928. Since then the Commission has had a close relationship with succeeding Congresses, and it has also been looked to as the appropriate body to give general guidance on the more widespread use of radiation sources caused by the rapid developments in the field of nuclear energy. The Commission wishes to maintain fully its traditional contact with medical radiology, and to fulfil its responsibilities to the medical profession. In addition, the Commission recognizes its responsibility to other professional groups and its obligation to provide guidance within the field of radiation protection as a whole.

The policy adopted by the Commission in preparing its recommendations is to deal with the basic principles of radiation protection, and to leave to the various national protection committees the responsibility of introducing the detailed technical regulations, recommendations, or codes of practice best suited to the needs of their individual countries.

The Commission has kept its recommendations continually under review in order to cover the increasing number and scope of potential radiation hazards, and to amend safety factors in the light of new knowledge concerning the effects of ionizing radiations.

Since the Ninth International Congress of Radiology in Munich the Commission has published two reports, entitled " Permissible Dose for Internal Radiation " (ICRP Publication 2), and " Protection Against X-rays up to Energies of 3 MeV and Beta- and Gamma-rays from Sealed Sources " (ICRP Publication 3). The latter report is essentially a code of practice for medical radiologists.

In 1959 the International Commission on Radiological Protection and the International Commission on Radiological Units and Measurements were jointly asked by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) to prepare a report dealing with somatic effects of medical radiation exposures. A study group was appointed at the Munich meeting; it met in 1960, and prepared a report entitled " Exposure of Man to Ionizing Radiation Arising from Medical Procedures, with Special Reference to Radiation-Induced Diseases ". The report was submitted to the UNSCEAR at the end of 1960, and in 1961 it was published in *Physics in Medicine and Biology* **6**, No. 2 (Taylor and Francis Ltd., London).

Committee reports have also been prepared on:

(*a*) Protection Against Electromagnetic Radiation above 3 MeV and Electrons, Neutrons and Protons;

(*b*) Handling and Disposal of Radioactive Materials in Hospitals and Small Establishments;

(*c*) RBE (Relative Biological Effectiveness).*

It is expected that these reports will be published during 1964.

The Commission has maintained close contact with the World Health Organization (WHO) and with the International Atomic Energy Agency (IAEA), with both of which the Commission has an official relationship. The Commission has been represented by observers at a number of meetings organized by the WHO and the IAEA. Co-operation has also been maintained with the International Labour Office (ILO), the Food and Agriculture Organization, and the UNSCEAR, all of which have been invited to send observers to technical meetings of the Commission and its committees. The Commission has been represented at all meetings of the UNSCEAR during the period 1960–1962.

During the period between the two last Congresses, the ILO has prepared an international instrument consisting of a Radiation Protection Convention (No. 115) supplemented by a Recommendation (No. 114). The Commission realizes that the reference to its work, in paragraphs 3,

* Published in *Health Physics* **9**, No. 4 (1963).

4 and 5 of the Recommendation, increases its responsibility and adds to the importance of keeping its recommendations continually under review.

Grants of money have been made to the Commission by a number of organizations. The Ford Foundation has allocated $250,000, to be paid over a period of 5 years. The World Health Organization contributed $9,000 in the years 1960 and 1961, and $10,000 in 1962 and 1963. The International Society of Radiology gave $3,000 for the period between the 1959 and 1962 Congresses and $3,000 for 1963. A sum of $10,000 was received from the UNSCEAR in connection with the work of the Joint Study Group described above. The International Atomic Energy Agency has contributed $6,000 for 1963. The Commission wishes to express its sincere appreciation to all these organizations.

A meeting of the Commission and its committees was held in Stockholm in May 1962. The Commission also met in Ottawa in executive sessions immediately before the Tenth International Congress of Radiology; at these meetings the Commission prepared the present report incorporating its latest recommendations as well as amendments to previous recommendations.

Since the meeting in Munich the Commission has suffered the death of two of its most distinguished members; its Chairman Emeritus, Sir Ernest Rock Carling, and its Vice-Chairman Emeritus, Professor G. Failla. The Commission owes a great debt of gratitude to them for their invaluable work during the most significant years in the history of radiation protection.

During the preparation of this statement the ICRP has had the following composition:

1959–1962

R. M. Sievert, *Chairman* (Sweden)
E. E. Pochin, *Vice-Chairman* (Great Britain)
W. Binks (Great Britain)
L. Bugnard (France)
H. Holthusen (Germany)
J. C. Jacobsen (Denmark)
R. G. Jaeger (Germany)
J. F. Loutit (Great Britain)
K. Z. Morgan (U.S.A.)
H. J. Muller (U.S.A.)
R. S. Stone (U.S.A.)
L. S. Taylor (U.S.A.)
E. A. Watkinson (Canada)

Sir Ernest Rock Carling, *Chairman Emeritus* (Great Britain)—Deceased 1960
G. Failla, *Vice-Chairman Emeritus* (U.S.A.)—Deceased 1961

B. Lindell, *Secretary* (Sweden)

1962

E. E. Pochin, *Chairman* (Great Britain)
L. Bugnard, *Vice-Chairman* (France)
W. Binks (Great Britain)
O. Hug (Germany)
H. Jammet (France)
B. Lindell (Sweden)
J. F. Loutit (Great Britain)
K. Z. Morgan (U.S.A.)
H. J. Muller (U.S.A.)
R. M. Sievert (Sweden)
C. G. Stewart (Canada)
R. S. Stone (U.S.A.)
L. S. Taylor (U.S.A.)

F. D. Sowby, *Scientific Secretary* (Canada)

During the Stockholm meeting in May, 1962, the Commission decided to reorganize the structure of its committees. The previous committees were dissolved at the time of the Tenth International Congress of Radiology and four new committees were established to review various topics of interest to the Commission:

1. Radiation Effects
2. Internal Exposure
3. External Exposure
4. Application of Recommendations.

The following have accepted invitations to serve as members of these committees:

Committee 1

J. F. LOUTIT, *Chairman* (Great Britain)
F. DEVIK (Norway)
A. R. GOPAL-AYENGAR (India)
O. HUG (Germany)
L. F. LAMERTON (Great Britain)
J. LEJEUNE (France)
H. B. NEWCOMBE (Canada)
R. SCOTT RUSSELL (Great Britain)
A. C. UPTON (U.S.A.)

Committee 2

K. Z. MORGAN, *Chairman* (U.S.A.)
W. BINKS (Great Britain)
A. M. BRUES (U.S.A.)
B. CHR. CHRISTENSEN (Denmark)
M. IZAWA (Japan)
M. LAFUMA (France)
L. D. MARINELLI (U.S.A.)
W. G. MARLEY (Great Britain)
E. E. POCHIN (Great Britain)
V. SHAMOV (U.S.S.R.)
W. S. SNYDER (U.S.A.)
C. G. STEWART (Canada)

Committee 3

E. E. SMITH, *Chairman* (Great Britain)
J. DUTREIX (France)
R. G. JAEGER (Austria)
L.-E. LARSSON (Sweden)
A. PERUSSIA (Italy)
E. DALE TROUT (U.S.A.)
B. M. WHEATLEY (Great Britain)
H. O. WYCKOFF (U.S.A.)

Committee 4

H. JAMMET, *Chairman* (France)
D. J. BENISON (Argentina)
G. C. BUTLER (Canada)
H. DAW (U.A.R.)
H. J. DUNSTER (Great Britain)
B. LINDELL (Sweden)
D. MECHALI (France)
C. POLVANI (Italy)
P. RECHT (Belgium)
C. P. STRAUB (U.S.A.)
E. G. STRUXNESS (U.S.A.)
F. WESTERN (U.S.A.)

This reorganization does not change, in essence, the scope of program of the previous Committees I and II, but the old Committees III, IV and V and the ICRP/ICRU Committee on RBE are not included as such under the new structure. All problems relating to external exposure, both for quantum and for particulate radiation at any energy, will now be considered within the new Committee 3. Special *ad hoc* task groups will be set up from time to time to deal with specific problems.

The Committees I–V and the *ad hoc* Committee on RBE had the following composition during the period 1959–1962.

Committee I (Advisory Committee on Biology)

J. F. LOUTIT, *Chairman* (Great Britain)
A. A. BUZZATI-TRAVERSO (Italy)
J. A. COHEN (The Netherlands)
F. DEVIK (Norway)
A. R. GOPAL-AYENGAR (India)
L. F. LAMERTON (Great Britain)
J. LEJEUNE (France)
H. B. NEWCOMBE (Canada)
J. NIELSEN (Denmark)
R. SCOTT RUSSELL (Great Britain)
A. C. STEVENSON (Great Britain)
A. C. UPTON (U.S.A.)
S. WARREN (U.S.A.)

Committee II (Protection against radiation from internal radioactive substances)

K. Z. MORGAN, *Chairman* (U.S.A.)
W. BINKS (Great Britain)
A. M. BRUES (U.S.A.)
B. CHR. CHRISTENSEN (Denmark)
M. IZAWA (Japan)
W. H. LANGHAM (U.S.A.)
L. D. MARINELLI (U.S.A.)
W. G. MARLEY (Great Britain)
M. POBEDINSKI (U.S.S.R.)
E. E. POCHIN (Great Britain)
W. S. SNYDER (U.S.A.)
C. G. STEWART (Canada)

Committee III (Protection against X-rays and electrons up to energies of 3 MeV and beta- and gamma-rays from sealed sources)

R. G. JAEGER, *Chairman* (Germany)
E. E. SMITH, *Vice-Chairman* (Great Britain)
C. B. BRAESTRUP (U.S.A.)
E. D. TROUT (U.S.A.)
C. GARRETT (Canada)
F. GAUWERKY (Germany)
H. HOLTHUSEN (Germany)
L. LORENTZON (Sweden)
S. B. OSBORN (Great Britain)
C. POLVANI (Italy)
D. J. STEVENS (Australia)
H. O. WYCKOFF (U.S.A.)
J. ZAKOVSKY (Austria)
A. ZUPPINGER (Switzerland)

Committee IV (Protection against electrons and electromagnetic radiation above 3 MeV, neutrons and radiation from heavy particle accelerators)

G. J. NEARY, *Chairman* (Great Britain)
J. W. BOAG (Great Britain)
F. HERČÍK (Czechslovakia)
G. S. HURST (U.S.A.)
H. E. JOHNS (Canada)
G. JOYET (Switzerland)
W. H. KOCH (U.S.A.)
J. S. LAUGHLIN (U.S.A.)
C. A. TOBIAS (U.S.A.)
M. TUBIANA (France)
B. M. WHEATLEY (Great Britain)
K. G. ZIMMER (Germany)

Committee V (Handling of radioactive isotopes and disposal of radioactive waste)

C. P. STRAUB, *Chairman* (U.S.A.)
L. R. DONALDSON (U.S.A.)
H. J. DUNSTER (Great Britain)
H. JAMMET (France)
A. W. KENNY (Great Britain)
C. A. MAWSON (Canada)
A. A. PERUSSIA (Italy)
E. H. QUIMBY (U.S.A.)
F. D. SOWBY (Canada)
E. G. STRUXNESS (U.S.A.)
F. WESTERN (U.S.A.)

ICRP/ICRU Committee on RBE (Relative biological effectiveness)

L. F. LAMERTON, *Chairman* (Great Britain)
J. F. LOUTIT (Great Britain)
H. H. ROSSI (U.S.A.)
W. S. SNYDER (U.S.A.)
G. J. NEARY (Great Britain)
O. HUG (Germany)
H. I. KOHN (U.S.A.)
H. QUASTLER (U.S.A.)
M. TUBIANA (France)
A. C. UPTON (U.S.A.)

RULES GOVERNING THE SELECTION AND WORK OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

1. (a) The International Commission on Radiological Protection (ICRP) shall be composed of a Chairman and not more than twelve other members. The selection of the members shall be made by the ICRP from nominations submitted to it by the National Delegations to the International Congress of Radiology and by the ICRP itself. The selections shall be subject to approval by the International Executive Committee (IEC) of the Congress. Members of the ICRP shall be chosen on the basis of their recognized activity in the fields of medical radiology, radiation protection, physics, health physics, biology, genetics, biochemistry and biophysics, with regard to an appropriate balance of expertise rather than to nationality.

(b) The membership of the ICRP shall be approved during each International Congress for service until the end of the succeeding Congress, or until new members are appointed. Not less than two but not more than four members shall be changed at any one Congress. In the intervening period vacancies may be filled by the ICRP.

(c) In the event of a member of the ICRP being unable to attend the ICRP meetings, a substitute may be selected by the ICRP as a temporary replacement. Such a substitute shall not have voting privileges unless specifically authorized by the ICRP.

(d) The ICRP shall be permitted to invite individuals to attend its meetings to give special technical advice. Such persons shall not have voting privileges, but their opinions may be recorded in the minutes.

2. The Chairman shall be elected by the ICRP from among its members to serve until the end of the succeeding Congress, or until his successor is elected. The choice shall not be limited to the country in which it is proposed to hold the succeeding Congress. The Chairman shall be responsible for reporting the proceedings and recommendations of the ICRP at the next Congress.

3. The ICRP shall elect from among its members a Vice-Chairman who will serve in the capacity of Chairman in the event that the Chairman is unable to perform his duties.

4. Minutes of meetings and records of the ICRP shall be made by a Scientific Secretary selected by the Chairman of the ICRP, subject to the approval of its members. The Scientific Secretary need not be a member of the ICRP. The records of the ICRP shall be passed on to the succeeding Scientific Secretary.

5. The Chairman, in consultation with the Vice-Chairman and the Scientific Secretary, shall prepare a program to be submitted to the Commission for discussion at its meetings. Proposals to be considered shall be submitted to the Chairman for circulation to all members of the ICRP and other specially qualified individuals at least two months before any meeting of the ICRP.

6. Decisions of the ICRP shall be made by a majority vote of the members. A minority opinion may be appended to the minutes of a meeting if so desired by any member, upon his submission of the same in writing to the Scientific Secretary.

7. The ICRP may establish such committees as it deems necessary to perform its functions.

3. THE 1962 EXPLANATORY STATEMENTS AND AMENDMENTS TO THE 1958 RECOMMENDATIONS* AND TO THE 1959 ADDENDUM

RBE AND QF

ALL doses specified in the Commission's recommendations are expressed in rems,† which implies that the absorbed dose (expressed in rads) should be multiplied by an appropriate weighting factor. Previously the weighting factor was termed the " RBE ". The use of this term both in radiobiology and for protection purposes presents certain problems, which are discussed in detail in the Report of the ICRP/ICRU Committee on RBE (*Health Physics* **9**, No. 4 (1963)).

The Commission now endorses the following statement, taken from Report 10a‡ of the International Commission on Radiological Units and Measurements (ICRU):

> The term " RBE dose " has in past publications of the Commission not been included in the list of definitions but was merely presented as a " recognized symbol ". In its 1959 report the Commission also expressed misgivings over the utilization of the same term, " RBE ", in both radiobiology and radiation protection. It now recommends that the term RBE be used in radiobiology only and that another name be used for the linear-energy-transfer-dependent factor by which absorbed doses are to be multiplied to obtain for purposes of radiation protection a quantity that expresses on a common scale for all ionizing radiations the irradiation incurred by exposed persons. The name recommended for this factor is the *quality factor* (*QF*). Provision for other factors are also made. Thus a *distribution factor* (*DF*) may be used to express the modification of biological effect due to non-uniform distribution of internally deposited isotopes. The product of absorbed dose and modifying factors is termed the *dose equivalent* (*DE*). As a result of discussions between ICRU and ICRP the following formulation has been agreed upon:
>
> *The Dose Equivalent*
>
> 1. For protection purposes it is useful to define a quantity which will be termed the " dose equivalent " (*DE*).
> 2. (*DE*) is defined as the product of absorbed dose, *D*, quality factor (*QF*), dose distribution factor (*DF*), and other necessary modifying factors.
>
> $$(DE) = D(QF)(DF) \ldots$$
>
> 3. The unit of dose equivalent is the " rem ". The dose equivalent is numerically equal to the dose in rads multiplied by the appropriate modifying factors.

With regard to the actual values of *QF* that should be used for radiation protection calculations, the Commission endorses the " RBE " values which it published in 1955 (*Brit. J. Radiol.*, Supplement 6). These values are related to the LET of the radiation independdently of other exposure factors. It is recommended that with regard to specification of radiation quality the basic parameter be LET_∞ (the " Stopping Power "), defined as the energy loss per unit distance of the charged particles originally set in motion by electromagnetic radiation or neutrons, or of the charged particles which originate in radiation sources (alpha-rays, beta-rays, etc.), i.e. the delta-rays are not counted as separate tracks. The *DE* (expressed in rems) is obtained by summation of the products of doses delivered at any LET and the appropriate *QF*-factors, as well as any other factors recommended by the Commission, for example the " *n* " factor (see discussion below). Simplifications of this procedure are allowed provided they do not result in an underestimate of the true *DE*. An example of such a simplification is the use of a single value of *QF* for all fast neutrons.§

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* ICRP Publication 1.

† The term " dose ", when used in this context, is now to be understood as " dose equivalent " (see discussion below).

‡ United States National Bureau of Standards Handbook 84.

§ Note the special case of the lens of the eye (*q.v.*).

The relationship between *QF* and LET recommended for radiation protection calculations is the following:

TABLE I. LET–*QF* RELATIONSHIP

LET_∞ (keV per micron in water)	*QF*
3.5 or less	1
3.5–7.0	1–2
7.0–23	2–5
23–53	5–10
53–175	10–20

In practice the *QF* for X- and gamma-rays is taken as unity, and for electrons it is only greater than unity at very low energies.

Most practical *DE* problems consist in the evaluation of the hazard due to a mixture of neutrons and gamma-radiation. The *QF* of neutrons as a function of neutron energy has been evaluated for neutron energies up to 10 MeV (United States National Bureau of Standards Handbook 63). If the neutron energy distribution is known, the absorbed dose due to neutrons may then be multiplied by an appropriate *QF* to obtain the *DE*. If the precise neutron energy is unknown the absorbed doses due to neutrons and gamma-rays should be evaluated separately. The sum of the neutron doses multiplied by 10* and the gamma-ray doses multiplied by 1 may be considered an upper limit of the *DE*. Finally, the simplest approach is merely to measure the total absorbed dose and to multiply it by a *QF* of 10. While being the simplest, this method may result in an overestimate by a factor that can approach 10. (A detailed discussion of the measurement of neutron flux and neutron dose is to be found in United States National Bureau of Standards Handbook 72).

For heavy recoil nuclei the LET may be greater than 175 keV/μ. There is however experimental evidence that even in this case the *QF* probably does not exceed 20. This value is therefore considered to be appropriate for heavy recoil nuclei.

For internal exposure *QF* should be taken as 1 for β^-, $\beta+$, gamma- and X-radiation and conversion electrons (except in the case of β^-, $\beta+$ and e^- radiations with maximum energy, E_m, $\leqq$ 0.03 MeV, for which the *QF* is taken to be 1.7), 10 for alpha-particles and 20 for fission fragments and for nuclei recoiling during alpha-emission.

There are certain radiation exposure conditions in protection work where the *QF* concept as outlined above is either inapplicable or can only be applied with major qualifications. Important examples are those where gross non-uniformity of dose distribution occurs, as with the bone-seeking radioactive nuclides or with radioactive particles in the lung. For the bone-seekers special methods have been developed for the determination of maximum permissible body-burdens, involving the use of an additional factor "*n*", the "relative damage factor" (see Report of Committee II, ICRP Publication 2). The concept of *DE* for the bone-seekers, in relation to its use with external radiation, presents a number of problems, on which further work is required.

In the case of the lung, an estimate of the *DE* to the critical tissue determined merely by the product of *QF* and mean dose may be greatly in error, but further experimental advance is needed before a better estimate can be made.

THE LENS OF THE EYE AS A CRITICAL ORGAN

In the 1958 Recommendations the blood-forming organs, the gonads and the lenses of the eyes were regarded as the most radiosensitive tissues. There is evidence indicating that the lens may be specially radiosensitive only to particulate radiation of high LET (e.g. neutrons having an energy of about 1 MeV). On the evidence available at present the lens seems not to assume a greater importance than

* Note the special case of the lens of the eye (*q.v.*).

other tissues when X-, gamma- and beta-radiations only are concerned. The Commission therefore recommends that the lenses of the eyes no longer be considered as tissues to which the formula applies, but that the maximum permissible dose shall be 4 rems/13 weeks, corresponding to a maximum permissible annual dose of 15 rems. However, in the case of particulate radiation of high LET a special *QF* of 30 shall be used, instead of the usual value of 10.

The *QF* values to be used for irradiation of the lens by radiations other than those mentioned above are still under consideration by the Commission.

SIGNIFICANT AREAS AND VOLUMES

The Commission's 1955 recommendations (*Brit. J. Radiology*, Supplement 6) included a reference to the volume or area over which the dose should be averaged in the computation of maximum permissible tissue doses. This reference has not been republished in subsequent recommendations and it is recommended that the following principles should apply.

Within permissible dose ranges specified for occupational exposure, when the object of control is to reduce to a very low order of magnitude the risk of late effects (such as malignant change from an accumulated dose of radiation) it is justifiable to consider the average dose to the whole organ or tissue. This has practical advantages in that the significant volume can be taken as that of the organ or tissue under consideration. In fact, this principle has necessarily been used already in calculating permissible concentrations of radioactive nuclides in tissues.

When skin is contaminated with radioactive material, it is considered that the previous recommendation of a significant area of 1 cm^2 might be too restrictive. It is therefore recommended that the significant area in such cases be taken to be of the order of 30 cm^2. This is a practicable recommendation from the standpoint of procedures used to determine the degree of contamination of the skin.

In other cases of external exposure, especially when the distance to the source is very short or when the exposed area is very small, it would not be appropriate to recommend the dose to be assessed as the average over 30 cm^2; for these cases it is recommended that the previous practice of referring to 1 cm^2 be maintained.

"PERMISSIBLE DOSE" AND "MAXIMUM PERMISSIBLE DOSE"

In the chapter on "Basic Concepts" (paragraphs 29–32 of the 1958 Recommendations) the Commission defined what it considers to be a *permissible* dose:

"(29) Any departure from the environmental conditions in which man has evolved may entail a risk of deleterious effects. It is therefore assumed that long continued exposure to ionizing radiation additional to that due to natural radiation involves some risk. However, man cannot entirely dispense with the use of ionizing radiations, and therefore the problem in practice is to limit the radiation dose to that which involves a risk that is not unacceptable to the individual and to the population at large. This is called a 'permissible dose'.

"(30) The permissible dose for an *individual* is that dose, accumulated over a long period of time or resulting from a single exposure, which, in the light of present knowledge, carries a negligible probability of severe somatic or genetic injuries; furthermore, it is such a dose that any effects that ensue more frequently are limited to those of a minor nature that would not be considered unacceptable by the exposed individual and by competent medical authorities.

"(31) Any severe somatic injuries (e.g. leukemia) that might result from exposure of individuals to the permissible dose would be limited to an exceedingly small fraction of the exposed group; effects such as shortening of life span, which might be expected to occur more frequently, would be very slight and would likely be hidden by normal biological variations. The permissible doses can therefore be expected to produce effects that could be detectable only by statistical methods applied to large groups.

"(32) The permissible dose to the gonads for the *whole population* is limited primarily by considerations with respect to genetic effects (see paragraphs 58–65)."

On the basis of the above criteria, the Commission has given recommendations with regard to the *maximum* dose which, still fulfilling the above requirements, should be permitted under various circumstances. The Commission has balanced as far as possible the risk of the exposure against the benefit of the practice, and has also considered the possible danger involved in remedial actions once the exposure has occurred. This dose has been called the *maximum permissible dose.*

The basis of the Commission's recommendations is that any exposure to radiation may carry some risk. The assumption has been made that, down to the lowest levels of dose, the risk of inducing disease or disability in an individual increases with the dose accumulated by the individual, but is small even at the maximum permissible levels recommended for occupational exposure. This assumption is supported by the limited statistics available which indicate that for radiation workers of the last generation, exposed, subject to the maximum permissible levels of that time, the risks of somatic effects are comparable with or less than those of the majority of other trades and professions, and would therefore be considered as not unacceptable. The Commission similarly considered the risk of somatic effects in individuals within certain population groups, and recommended maximum permissible levels for these individuals.

With regard to genetic effects, the Commission assumed that the genetic burden to a population will be proportional to the genetic dose received by that population (see paragraph 63 of the 1958 Recommendations). The Commission therefore recommended a maximum permissible genetic dose of 5 rems,* on the basis that the resulting burden to society would be " tolerable and justifiable in view of the benefits that may be expected to accrue from the expansion of the practical application of ' atomic energy ' ".

The implication of a maximum permissible dose is that it must be capable of being controlled. It is therefore clear that the Commission's recommended maximum permissible doses are appropriate for those conditions in which the levels can be controlled. However, in the case of accidents and of environmental contamination when exposures may not be subject to control, the concept of a fixed maximum permissible dose ceases to be meaningful. Instead, other considerations arise, such as the need to balance the risk from radiation against the risks of particular countermeasures. The principles upon which these risks might be assessed and balanced are still under consideration.

* From all sources additional to natural background plus the lowest practicable contribution from medical exposure.

DOSE-RATE EFFECTS

(*a*) Somatic Effects

It has long been recognized that the effects of radiation may be dependent not only on the accumulated dose received but also on the way in which this total is fractionated and on the dose-rate at which each fraction is given. This applies particularly to radiation of low LET such as X-rays, gamma-rays and beta-radiation which are by far the commonest radiations encountered in occupational practice at the present time. It appears possible on some theoretical and experimental grounds that when either the total dose or the dose-rate is very low any effects will be directly proportional to the total dose and independent of dose-rate. This assumption is implicit in past recommendations on permissible levels and although confirmatory proof is lacking it is believed to be a reasonable basis for assessment.

(*b*) Genetic Effects

A linear dose-effect relationship unaffected by dose-rate has been generally accepted in the past for gene-mutations. Recent experimental work has shown, however, that at intermediate and higher levels of dose-rate the number of mutations produced in test-subjects may not be independent of dose-rate. Because of the importance of the genetic effect the Commission has made a special survey of recent work. This survey indicates that evidence for dependence of mutation frequency on dose-rate comes at present almost entirely from a study of seven gene-loci in spermatogonial cells and oocytes of the mouse. For insects there is not yet clear evidence of a difference in effectiveness of acute

and chronic doses that cannot be ascribed to selection. No general relationship appears therefore to hold for all species, and the Commission does not at present modify its recommendations to allow for dose-rate effects in man.

CATEGORIES OF EXPOSURE

In paragraph 36 of the 1958 Recommendations the Commission referred to certain categories of exposed *individuals*, essentially within three groups:

A: Occupationally exposed individuals
B: Special groups
C: The population at large.

Group B was subdivided into three subgroups, namely:

"B(*a*): Adults who work in the vicinity of controlled areas, but who are not themselves employed on work causing exposure to radiation,
"B(*b*): Adults who enter controlled areas occasionally in the course of their duties, but are not regarded as radiation workers,
"B(*c*): Members of the public living in the neighborhood of controlled areas."

In the 1958 Recommendations the Commission made certain recommendations regarding the exposure of individuals in groups A and B. No recommendation was given in the 1958 Recommendations with regard to the dose to individuals in the population at large, but in an additional paragraph in the 1959 Addendum it was recommended that the maximum dose to these individuals should be equal to the maximum recommended for individuals within group B(c).

The Commission recognizes that the above description of the categories of exposure of *individuals* may have been open to misunderstanding, and in particular that the term "exposure of special groups" may have been taken to imply that maximum permissible doses for individuals in this category of exposure refer to a dose averaged over the group. To avoid this misunderstanding the above categories of exposure have been slightly revised to conform with current practice and the present recommendations relate to exposure of three categories of individuals.*

The first category consists of individuals who are occupationally exposed to radiation.†

The second category comprises adults who work in the vicinity of controlled areas or who enter controlled areas occasionally in the course of their duties, but who are not themselves employed on work involving exposure to radiation.

The third category consists of individual members of the population at large (including persons living in the neighborhood of controlled areas). The reader is referred to paragraphs 45–57a in Section 4(c) of this report for the maximum permissible doses applicable to individuals in these categories.

In addition to recommending maximum permissible doses for individuals, the Commission also gives separate recommendations about the average exposure to the population as a whole, determined by exposures of the individuals within the above categories (see paragraphs 58–70c of Section 4(c) of this report).

EXPOSURE OF WOMEN OF REPRODUCTIVE AGE

Occupational Exposure

The Commission has reviewed the questions involved in the occupational exposure of pregnant women, and the associated possibilities of somatic damage to foetal tissues which were referred to in the 1959 Addendum to ICRP Publication 1 (1958 Recommendations). In this connection, consideration must be given to exposure during a period of up to 2 months before a pregnancy is recognized, and to exposure during the remainder of the pregnancy.

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* It should be noted that exposures within the first two categories as defined here correspond to the two classes of exposure used in the International Labour Office's Radiation Protection Convention, namely (1) Workers directly engaged in radiation work, and (2) Workers not directly engaged in radiation work.

† The term "occupational exposure" refers to exposure within controlled areas, i.e. where workers could receive doses in excess of 1.5 rems/year (paragraphs 37 and 71 of Section 4 of this report).

During the first of these periods, many of the processes of embryogenesis and organogenesis are occurring; this is a stage when the embryo is particularly sensitive to radiation. It is also evident that any recommendations for this period must in practice apply to all women of reproductive age.

In the 1959 Addendum to ICRP Publication 1, the Commission made the following recommendation with regard to the receipt of quarterly doses of 3 rems, referred to in paragraph 49 of ICRP Publication 1:

> If necessary, the 3 rems may be received as a single dose, but as the scientific knowledge of the biological effects of differing dose-rates is scant, single doses of the order of 3 rems should be avoided as far as practicable, especially in the case of women of reproductive age.

The Commission is now of the opinion that the recommendation given in paragraph 49 of ICRP Publication 1, for dose accumulation at rates up to 3 rems per quarter, should not apply in circumstances involving abdominal exposure of women of reproductive age. The Commission now recommends that women of reproductive age should be occupationally employed only under conditions where the exposure of the abdomen is limited to 1.3 rems in a 13-week period, corresponding to 5 rems per year delivered at an even rate. Under these conditions the dose to an embryo during the first two months of pregnancy would normally be less than 1 rem, a dose which the Commission considers to be acceptable.

After two months it is likely that a pregnancy would be recognized by the woman herself or by her physician. While many of the critical stages of embryogenesis are now past, more recent evidence indicates that even at this stage the fetus is still particularly radiosensitive. For instance, investigation has shown that exposure of fetuses to doses of a few rads of X-rays can give rise to detectable somatic mutations, resulting in the condition of pigment mosaicism, although this condition does not appear to be detrimental. Furthermore, the possible induction of leukaemia and other malignant conditions has to be considered. Surveys of such conditions in children have in the past led to conflicting conclusions. Recent studies, however, do indicate that exposure of the fetus *in utero* to doses of a few rads of X-rays might somewhat increase the incidence of malignant disease within the subsequent decade.

For occupational exposure, therefore, it is now recommended that when a pregnancy has been diagnosed, arrangements be made to ensure that the exposure of the woman be such that the average dose to her fetus during the remaining period of the pregnancy does not exceed 1 rem. Under conditions in which the foetal dose may approximate to that received by the woman, for example when the abdomen is exposed to penetrating radiation, this recommendation will normally be met if the woman is not exposed at rates greater than those applicable to members of groups B(a) and B(b) as specified in ICRP Publication 1, since such workers may not be exposed at rates greater than 1.5 rems per year (see paragraph 54).

Under conditions in which the fetal dose will be considerably less than that received by the woman, as for example when working with diagnostic X-ray equipment of 150 kv or less, or where the abdomen is protected from or not exposed to the radiation, the recommendation may be satisfied by continuing occupational exposure of the woman at a rate not exceeding 1.3 rems per 13 weeks.

Exposure of Individuals in Special Groups

With regard to pregnant women exposed under the conditions which relate to the former groups B(a) and B(b), it is considered that no special precautions need to be taken.

Radiological Examinations of Women of Reproductive Age

The Commission wishes to call attention to reports of embryonic and fetal sensitivity to ionizing radiation and to emphasize that the possibility of pregnancy must be taken into account by the attending physician when deciding on radiological examinations that involve the lower abdomen and pelvis of women of reproductive age. The Commission also wishes to point out that the ten-day interval following the onset of menstruation is the only

time when it is virtually certain that women of such age are not pregnant. Therefore, it is recommended that all radiological examinations of the lower abdomen and pelvis of women of reproductive age, that are not of importance in connection with the immediate illness of the patient, be limited in time to this period when pregnancy is improbable. The examinations that should be delayed to await the onset of the next menstruation are those that could without detriment be delayed till the conclusion of a pregnancy or at least until its latter half.

REWORDING AND EXTENSION OF PARAGRAPH 52e AND 52g OF THE 1959 ADDENDUM TO ICRP PUBLICATION 1, CONCERNING SHORT-TERM EXPOSURES AND EMERGENCY WORK

The recommendations on short-term exposure to radioactive materials given in the above-mentioned paragraphs have been useful in establishing general principles of interpretation for such exposure. However, experience has indicated that the restriction on exposure as given in the last paragraph of 52g might be dealt with more effectively, in the case of long-lived bone-seeking nuclides, by using the method described in paragraph 86a (*q.v.*). Also the wording of paragraphs 52e and 52g has been slightly altered to make it entirely clear that short-term intakes are being compared with intakes at the MPC levels and not with the resulting body-burden, and that hazards not due to radiation may require a separate assessment. Therefore, paragraph 52e is replaced by the following statement:

> (52e) One or more short-term exposures to radioactive materials within a period of 13 consecutive weeks are considered acceptable if the total *intake* of radioactive material during this period does not exceed the cumulative intake allowed when exposure occurs for 13 weeks at the maximum levels (MPC values) for occupational exposure given in the Report of Committee II (ICRP Publication 2). If significant exposure to external sources occurs concurrently, the quarterly intake referred to above should be estimated to make allowance for the dose equivalent delivered by external sources (ICRP Publication 2, page 24). The 50-year integrated dose to the critical organ from such an intake will not exceed 1.3 rems for the whole body, blood-forming organs or gonads, 8 rems for skin, thyroid and bone,* and 4 rems for other organs.

Because of the chemical toxicity of natural uranium, U^{238}, U^{236}, or U^{235} in soluble form in amounts permitted according to the above on the basis of radiological protection, the inhalation of uranium of any isotopic composition should not exceed 2.5 milligrams of soluble uranium in one day, or the ingestion averaged over 2 days should not exceed 150 milligrams of soluble uranium.† For insoluble forms of uranium, maximum intake shall be limited by the same rule that applies to other radioactive materials set forth above.

Because of the low specific activity of certain other radioactive materials with very long radioactive half-lives (e.g. Rb^{87}, In^{115}, Nd^{144}, Sm^{147}, Re^{187}, etc.), the mass or chemical toxicity will in general determine maximum rates of intake. Similar considerations will apply also to the values given in Table 1 of ICRP Publication 2. Paragraph 52g is replaced by the following statement:

> Emergency work involving exposure to radioactive materials at levels above the normal maximum permissible concentrations shall be planned on the basis that the total intake of radioactive material during the emergency period should not exceed the cumulative intake that would result from exposure for 1 year at the maximum levels (MPC values) for occupational exposure to such radioactive materials given in the Report of Committee II (ICRP Publication 2). If significant exposure to external sources might be expected to occur concurrently, the annual intake referred to above should be estimated to make allowance for the dose equivalent delivered by the external sources (ICRP Publication 2, page 24). The 50-year integrated dose to the critical organ from such an intake

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* The dose to bone is based on a body-burden of 0.1 μc of Ra^{226} (see Report of Committee II, ICRP Publication 2).

† This restriction on the ingestion of soluble form of uranium revises the maximum permissible concentration recommended in Table 1 of ICRP Publication 2 for the continuous ingestion of drinking water. The new values of MPC for uranium that result from taking into account the chemical toxicity of uranium are given in Part 5 of the present report (ICRP Publication 6).

will not exceed 5 rems for the whole body, blood-forming organs or gonads, 30 rems for skin, thyroid and bone,* and 15 rems for other organs.

When such an exposure has occurred, an estimate of the intake shall be entered in the individual's record, and action shall be taken appropriate to paragraphs 86 and 86a.

RECOMMENDATIONS FOR MAXIMUM PERMISSIBLE EXPOSURES FOR PERSONS NOT OCCUPATIONALLY EXPOSED

As indicated in the 1959 Addendum to ICRP Publication 1 " Interpretation of paragraph 68: The basis for recommended limits of permissible exposure of populations to man-made sources of ionizing radiations is the dose received by the various organs of the body and not the MPC values or other criteria by which the dose is controlled". The recommendations or suggestions in paragraphs 56, 57 and 68 of the Commission's 1958 Recommendations have been stated in terms of fractions of the occupational MPC values and are thus limiting for adults. In the introduction of the Report of Committee II (ICRP Publication 2) it is pointed out that when children (including infants and fetuses) are exposed, other adjustment factors taking account of organ size, daily intake, sex, etc. may be required. Thus the MPC values for individual children, infants and fetuses are obtained by multiplying one-tenth of the MPC values for occupationally employed adults (168 h/wk exposure) by these adjustment factors to ensure that recommended dose limits to the body organs of children, infants and fetuses are not exceeded. Paragraphs 55, 56 and 57 of the Commission's 1958 Recommendations are to be interpreted as limiting all doses to individuals of former group B(c) to one-tenth of the corresponding annual occupational doses, and paragraph 57a (a new section proposed in the 1959 Addendum) extended this limit to apply also to individual members of the population at large. This recommendation is confirmed with regard to exposures for which control can be exercised. In the case of accidents and of environmental radiation beyond regular control, special considerations arise (see the above discussion of permissible dose).

Paragraph 54 of ICRP Publication 1 stated the maximum permissible dose to the gonads, the blood-forming organs and the lenses of the eyes for individuals of former groups B(a) and B(b). The last sentence of paragraph 54 is to be interpreted to imply that the annual dose to all other organs and tissues, and to the hands and forearms, feet and ankles of individuals of these groups shall be limited to one-tenth of the corresponding annual occupational doses.

APPORTIONMENT OF TOTAL GENETIC DOSE—MEDICAL EXPOSURE

In the 1958 Recommendations (paragraph 70) the Commission referred to the upper limit of the estimates of the annual genetically significant dose from medical exposure, and noted that the highest levels could be reduced significantly by careful attention to techniques.

More recent estimates of the genetic dose from medical exposure, described in the 1962 report of UNSCEAR,* indicate that the actual dose may be considerably less than the highest levels referred to above. In addition, the 1962 UNSCEAR report referred to estimates, which have been made in two countries, of the extent by which a reduction in dose could be achieved without loss of necessary medical information.†

Paragraph 70 of the 1958 Recommendations concluded: " A certain allowance for medical exposure of populations must be made and may be made in the near future as the subject is being studied for the purpose of limiting such exposure to the minimum value consistent with medical requirements". It is clear that the permissible dose will depend upon the value of

* The dose to bone is based on a body-burden of 0.1 μc of Ra^{226} (see Report of Committee II, ICRP Publication 2).

* Estimates of the annual genetically significant dose from X-ray diagnosis in 14 countries ranged from 6 to 60 mrem.

† Ministry of Health, Department of Health for Scotland, Radiological Hazards to Patients. Second report of the Committee. HMSO (1960).

Larsson, L-E. *Acta Radiologica*, Supplement 157: 7-127 (1958).

the medical benefit to be derived, and future extensions in the use of radiological methods may confer greater benefit from their application than detriment from the necessary associated exposure to radiation. At the present time the Commission has decided to maintain its policy of not making numerical recommendations with regard to the appropriate genetic dose from medical exposures.

EMERGENCY EXPOSURE OF POPULATIONS

The Commission has considered the problem of emergency exposure of a local population after the accidental release of large quantities of radioactive material. In the 1959 Addendum to ICRP Publication 1 the Commission gave recognition to the 1959 British report* on the problem of *dietary contamination* by I^{131}, Sr^{89}, Sr^{90}, and Cs^{137}. In 1961 the British Medical Research Council published a report† in which the problem of *inhalation* of these same radionuclides is discussed. After reconsideration of the problem during the 1962 meeting in Stockholm the Commission recognizes that there are many difficulties and uncertainties that remain to be considered, but reaffirms its former position regarding the 1959 Report to the Medical Research Council and extends similar recognition to the 1961 Report as being a useful evaluation of this problem on the basis of our present limited knowledge.

NEW PARAGRAPH 86(a) CONCERNING THE ADDITION OF DOSES FROM EXTERNAL AND INTERNAL EXPOSURES (TO FOLLOW PARAGRAPH 86 OF THE 1958 RECOMMENDATIONS)

86(a) The Commission has considered the difficulty of making proper allowance for the addition of doses from penetrating external exposure and from internal exposure *in the case of long-lived bone-seeking isotopes*, in view of the use for them of the "n" factor. For these radionuclides the Commission recommends that

(i) If the estimated body-burden is less than one-half of the maximum permissible, no consequential restriction of external radiation exposure need be applied;

(ii) If the estimated body-burden is greater than one-half but less than the maximum permissible, the total body exposure to penetrating external radiation shall be limited to not more than 1.5 rems in any year; and if A years is the age of the individual when the body-burden was first found to exceed one-half the maximum permissible, then the total accumulated dose from such future exposure beyond age A shall not exceed $1.5(N - A)$ rems where N is the current age of the individual; if, however, at age B the body-burden is found to have dropped to less than one-half the maximum permissible value, the accumulated dose from future external total body exposure beyond age B shall not exceed $5(N - B)$ rems;

(iii) If the estimated body-burden equals or exceeds the maximum permissible, no occupational exposure to penetrating external radiation is permissible.

TISSUE DISTRIBUTION OF Cs^{137}

More recent and more extensive data on the distribution of Cs^{137} and stable caesium in various body tissues have indicated that the distribution is essentially homogeneous. Although the newer data do not significantly alter the MPC values, they lower the estimate of the associated dose to bone and to the blood-forming organs.

RECOMMENDATIONS ON MPC VALUES FOR Sr^{90}

Since the publication of the Report of Committee II (ICRP Publication 2) very extensive data on the human metabolism of strontium and calcium have become available, but there has been little new information on the hazard associated with a sustained maximum permissible body-burden of Sr^{90}. The Commission is, accordingly, not changing its recommendations concerning the permissible *body-burden* of Sr^{90} at this time. However, the Commission considers that the metabolic data

* Maximum permissible dietary contamination after the accidental release of radioactive material from a nuclear reactor; Report to the Medical Research Council by its Committee on Protection against Ionizing Radiations. (*Brit. Med. J.*, 1, 967–969, 11 April 1959).

† Maximum contamination of respirable air after an accidental release of radioiodine, radiostrontium and caesium-137; Report to the Medical Research Council by its Committee on Protection against Ionizing Radiations. (*Brit. Med. J.*, 576–579, 26 Aug. 1961).

provide a sounder basis for estimation of *MPC values* for Sr^{90}, with bone as the critical organ, than does the exponential model used previously in the recommendations. Extensive experimental data indicate that the strontium–calcium ratio of mineral derived from diet in newly formed bone is about 0.25 of the corresponding ratio in the normal human diet. Data are also available on the average concentrations of stable strontium and stable calcium in normal human diet and bone of large populations. Both sets of data indicate than an $(MPC)_w$ value of about 4×10^{-6} $\mu c/cm^3$ and an $(MPC)_a$ value of about 4×10^{-10} $\mu c/cm^3$ for occupational exposure (168-hour week) would correspond to the maximum permissible body-burden of 2 μc with bone as the critical organ. These values do not differ markedly from those resulting from the use of a power function model for retention of strontium as given in the Appendix of the Committee II Report (ICRP Publication 2). Thus three largely independent methods of estimation support the above MPC values, and therefore the Commission now recommends that these values be used as the basis for limiting occupational exposure to Sr^{90} with bone as the critical organ. The $(MPC)_w$ and $(MPC)_a$ values for occupational exposure (40-hour week) with bone as the critical organ are 1×10^{-5} $\mu c/cm^3$ and 1×10^{-9} $\mu c/cm^3$, respectively.

The MPC and body-burden values with total body as the organ of reference also have been revised on the basis of the above model (see Part 5 of this report). Similar considerations apply to the MPC values for Sr^{89} but result in values which do not differ significantly from those in the Report of Committee II (ICRP Publication 2).

STATEMENT ON $(MPC)_a$ FOR Rn^{222}

The Commission assumes that the biological hazard to man associated with a continued exposure to high concentrations of Rn^{222} and daughters in inspired air, is carcinoma of the bronchus. It is not at present aware of direct biological evidence on which to base a maximum permissible concentration of these radionuclides in air for continuous exposure. In 1959 it therefore made use of the experimental physical evidence available on the deposition in the bronchus of the daughters of Rn^{222} present in inspired air; this evidence was used to calculate a maximum permissible concentration of Rn^{222} and its daughters in inspired air; that is, the concentration that would deliver to bronchial mucosa a dose of 15 rems per year. Since the radiation dose-rate to bronchus that results from breathing a mixture of Rn^{222} and its daughter products depends on the fraction of RaA daughter-atoms unattached to condensation nuclei, the maximum permissible concentration of Rn^{222} and daughters depends on the magnitude of this fraction in the particular atmosphere considered. The recommendations of the Commission allow for appropriate adjustments of the MPC value for Rn^{222} and its daughter products, by taking into account the values of this fraction in particular atmospheres. The value of MPC for Rn^{222} and daughters quoted in Table 1 of the Report of Committee II (ICRP Publication 2) is based upon an assumption that this fraction is 10 per cent. The value of this fraction may differ in particular circumstances, and the implications of such differences are discussed on page 23 of the Report of Committee II (ICRP Publication 2). The Commission is not aware of new evidence that would lead it to revise this maximum permissible concentration in air for exposure to Rn^{222} and daughters.

4. RECOMMENDATIONS OF THE COMMISSION

A. PREFATORY REVIEW*

(1) Prior to the Geneva meeting of the Commission in April 1956, permissible levels of exposure to ionizing radiation had been expressed in terms of a dose in a rather short interval of time (1 day or 1 week), that is, essentially, in terms of an average dose-rate—the average referring to the temporal distribution of the dose in the specified interval of time. Implicitly, if not explicitly, it was assumed that if this average dose-rate was low enough, no appreciable bodily injury would become apparent in the lifetime of the individual. The assumption was based largely on radiological experience which indicated that substantial skin recovery occurred within a few months following a moderate therapeutic dose and that the latent period for some long-term effects of radiation (e.g. cancer of the skin) resulting from residual tissue damage, was longer the lower the dose (or dose-rate in the case of chronic exposure). Thus, in an occupationally exposed individual a long-term effect might not become apparent in his lifetime, even if a certain amount of permanent injury had occurred.

(2) The basic permissible weekly dose at that time was 0.3 rem/week. Assuming that a person was occupationally exposed at this rate (50 weeks a year) for 50 years, the permissible accumulated dose would be 750 rems in the most critical organs or essentially throughout the body. It was realized then that this constituted a " large " lifetime dose and an appropriate warning was included in the Commission's report of 1955.

(3) The general awareness of radiation hazards induced caution on the part of those responsible for the protection of workers. Administratively, liberal factors of safety were often used especially in large atomic energy installations. As a result it was found that in general the actual exposure of personnel was kept at levels much below the then existing permissible limits.

(4) At the 1956 meeting of the Commission it became evident that stricter recommendations were needed. The 1955 Conference on the Peaceful Uses of Atomic Energy had aroused great interest in the development of atomic power plants throughout the world. In time this would greatly increase the number of persons occupationally exposed and would also bring about actual or potential exposure of other persons and the population as a whole. More importantly, the pressure for producing power economically might well do away with the " safety factors " mentioned above. Also, the average duration of occupational exposure per individual worker might increase. On the biological side it was considered that perhaps " recovery " plays a less important part in the long-term effects of radiation to be expected from continued exposure at low levels, than was earlier supposed. Because of the larger number of persons who would be exposed, occupationally or otherwise, genetic damage assumed greater importance. This was accentuated in no small degree by the realization that in some countries the per capita genetic dose contributed by medical procedures was about the same as that contributed by background radiation.

(5) Statistical studies had shown that the incidence of leukemia in radiologists was significantly greater than in other physicians who presumably were not professionally exposed to radiation. Of necessity these radiologists included those who had practiced their speciality at the time when radiation protection was not very effectively carried out. Therefore, the accumulated doses received by those who developed leukemia may have been much higher than the 750 rems mentioned above. On the other hand, since most of the exposure of these radiologists resulted from diagnostic

* Reproduced from the Commission's 1958 Recommendations. Footnotes added in 1962.

procedures carried out with low voltage X-rays, the lifetime dose in the blood-forming organs may have been lower than 750 rems even if the skin dose, especially in some parts of the body, was much higher. The mechanism of leukemia induction by radiation is not known. It may be postulated that if the dose is lower than a certain threshold value no leukemia is produced. In this case it would be necessary to estimate the threshold dose and to make allowances for recovery, if any. There is not sufficient information to do this, but caution would suggest that an accumulated dose of 750 rems might exceed the threshold. The most conservative approach would be to assume that there is no threshold and no recovery, in which case even low accumulated doses would induce leukemia in some susceptible individuals, and the incidence might be proportional to the accumulated dose. The same situation exists with respect to the induction of bone tumors by bone-seeking radioactive substances.

(6) Presently available longevity studies differ as to whether there is a statistically significant life shortening in radiologists as compared to other specialists presumably not occupationally exposed to radiation. However, in mammals chronically exposed at different daily doses a definite effect on longevity becomes clearly apparent at the higher daily doses. If extrapolation to lower daily doses, and then to man, is justified, it may be concluded that occupational exposure at presently accepted permissible limits may entail some life shortening. This effect may be interpreted as a slight acceleration of the natural aging process.

(7) The effects just discussed illustrate the two different types of possible long-term somatic effect that must be considered in setting up permissible limits of exposure. The first type (leukemia) is a serious effect occurring in some individuals and, therefore, the aim of protection would be to reduce the incidence to the lowest practical limit. The second type (life shortening) is presumably an effect on every individual and, therefore, the aim of protection would be to reduce the degree of effect to the lowest practical value. The definition of permissible dose has been changed to include explicitly these two types of possible effect.

(8) Genetic effects manifest themselves in the descendants of exposed individuals. The injury, when it appears, may be of any degree of severity from inconspicuous to lethal. A slight injury will tend to occur in the descendants for many generations, whereas a severe injury will be eliminated rapidly through the early death of the individual carrying the defective gene. Thus the sum total of the effect caused by a defective gene until it is eliminated may be considered to be roughly the same. The main consideration in the control of genetic damage (apart from aspects of individual misfortune) is the burden to society in future generations imposed by an increase in the proportion of individuals with deleterious mutations. From this point of view it is immaterial in the long run whether the defective genes are introduced into the general pool by a few individuals who have received large doses of radiation, or by many individuals in whom smaller doses have produced correspondingly fewer mutations. However, even in this case it is desirable to limit the dose received by an individual.

(9) In view of the foregoing, recommendations are made in this report in terms of maximum permissible doses for individuals and for population groups. In either case limits are set on the basis of dose accumulated over a period of years rather than in terms of a weekly dose that could be received for an indefinite period of time. The concept of limiting the accumulated dose was introduced by the Commission at its 1956 meeting in Geneva. The limitation of accumulated dose suggested at the time corresponds roughly to a three-fold reduction in weekly dose, for example, in the case of whole body occupational exposure when the exposure takes place approximately at a constant rate.

(10) In practice the problem of chief concern is chronic exposure either at low dose rates or by intermittent small doses. Under these conditions it is reasonable to assume that the dose accumulated over a period of years is the controlling factor, *provided* the intermittent

doses are sufficiently small. Thus, in addition to limiting the accumulated dose it is necessary to limit the magnitude of a single dose (that is, a dose received in a short interval of time). Previously a single exposure equal to the maximum permissible weekly dose (" seven consecutive days ") was permitted. Following the same pattern, the single dose limit for occupational exposure recommended in the present report is expressed in terms of the maximum permissible dose accumulated in a period of " 13 consecutive weeks ". The recommended value for the relevant organ (e.g. 3 rems for the blood-forming organs) has been made as high as it appears prudent, in the light of present knowledge. The stipulation of any 13 *consecutive* weeks has been made to make sure that operations are carried out in such a way that intermittent doses approximating the full 13 week quota do not occur at short intervals.

(11) In the recommendations published in 1955 maximum permissible limits were set on the basis of doses received by certain organs and certain serious late effects known to occur in them with sufficiently large doses. Provisions were made by means of an arbitrary " dose distribution curve " (in the report of Committee I) to limit the dose in other organs and tissues. This was made necessary by the adoption of a maximum permissible dose for the skin twice as large as that for the blood-forming organs (with an assumed effective depth of 5 cm). In the present report separate recommendations are made for three groups of organs or tissues :

(a) Blood-forming organs, gonads and lenses of the eyes.*

(b) Skin and thyroid gland.

(c) All other organs or tissues, specifically as regards exposure essentially limited to the organ or tissue in question.

(12) For the blood-forming organs, gonads and the lenses of the eyes* the limits for occupational exposure are set in terms of the dose accumulated at various ages, according to the formula $D = 5(N - 18)$, where D is the dose in rems and N is the age in years, with the additional stipulation that the dose accumulated during any 13 consecutive weeks shall not exceed 3 rems.

(13) For the skin and the thyroid gland the limit for occupational exposure is set in terms of the dose accumulated during any 13 consecutive weeks, and the recommended value is 8 rems. This is derived from an average of 0.6 rem/week (the maximum permissible weekly dose formerly recommended for the skin of the whole body) which in 13 weeks amounts to 7.8 rems, and the nearest whole number is used to avoid the implication of greater accuracy than is warranted by present knowledge. The limit for the dose in these tissues accumulated in 1 year is $(0.6 \times 50) = 30$ rems. It should be noted that the new recommendation refers to the dose in the skin itself, irrespective of the dose distribution in the subcutaneous tissues. Therefore, the comparison should be made with the previous recommendation for exposure to radiation of very low penetrating power, for which the recommended limit was 1.5 rem/week. Accordingly, in this case also a reduction has been made in the accumulated dose, but the single exposure limit has been increased from 1.5 to 8 rems. This should provide more flexibility in practice than was possible formerly.

(14) For all organs and tissues of the body except the blood-forming organs, the gonads and the lenses of the eyes,* the limit for occupational exposure is set in terms of the dose accumulated during any 13 consecutive weeks. With the exception of the skin, the pertinent practical cases in this category relate to exposure from internal sources essentially limited to individual organs or tissues. The following points require consideration. Whereas in the case of the blood-forming organs, the gonads, the lenses of the eyes* and the skin, the objective of protection is to prevent or minimize definitely known types of injury, in the case of other organs the type of injury is not known. (Bone constitutes the only exception, in which case the relevant injury is cancer and permissible limits may be set on the basis of data furnished

* See footnote to paragraph 27.

by human subjects who accumulated radium in their skeletons.) Possibly, radiation in sufficient dosage may increase the incidence of cancer in one of these organs (e.g. the thyroid gland) or it may accelerate aging of the organ. In the absence of factual data, it was deemed prudent in earlier recommendations of the Commission to set the maximum permissible limit for these organs, when irradiated by internal sources, as low as that for the more sensitive organs such as the gonads, that is, 0.3 rem/week. When the exposure is essentially limited to *one organ* because of the more or less selective accumulation of a certain radioactive isotope therein, it is obvious that this limit embodies a factor of safety not present when the *whole body* is exposed at the same permissible limit. For this reason and the fact that none of these organs is known to be as sensitive as the blood-forming organs, the gonads and the lenses of the eyes,* the Commission has decided to retain the previously recommended maximum permissible dose of 0.3 rem/week for each organ singly (with some exceptions noted in the report of Committee II). However the limit is now expressed in terms of 13 consecutive weeks, which makes it 4 rems, in round figures, with an annual accumulated dose of 15 rems. Committee II has made the necessary adjustments to conform with the lower permissible limits now recommended for some organs and for what may be regarded as constituting "whole body" exposure (e.g. isotopes distributed throughout the body, or several isotopes present simultaneously, each concentrating significantly in a different organ).

(15) The Commission has given particular attention to the difficult problem of setting permissible limits for exposure of persons in the neighborhood of radiation installations. The chief obstacle is the almost complete lack of knowledge of the deleterious effects that may result from low level exposure starting at conception and continuing throughout life. It is reasonable to expect a more marked effect then in the case of exposure starting after the individual has reached maturity (for one thing, because the period of exposure is longer), but it is very difficult to decide what allowance to make. Guidance could be obtained from suitable experiments carried out with mammals and it is hoped that such studies will be undertaken soon in some laboratories. In the meantime caution is in order. The Commission recommends that provisions be made in a controlled area or areas to make sure that under normal operating conditions no child residing outside such controlled areas, receives more than 0.5 rem/year (in the appropriate organs) from radiation or radioactive material originating in the controlled area or areas. In practice it may be expected that while fluctuations in exposure rate would occur, they would not be such as to require special limitations. It will be noted that this is one-tenth of the *lowest* annual dose in any organ permitted for occupational exposure. It includes contributions made by external and internal sources but does not include doses contributed by natural background radiation or medical procedures.

(16) Special groups of *adults* in the vicinity of a controlled area are permitted to receive larger annual doses in the gonads, the blood-forming organs and the lenses of the eyes, by a factor of three (i.e. 1.5 rems). No biological significance should be attached to the magnitude of this factor, since present radiobiological information is grossly inadequate in this respect. The value recommended (1.5 rems/year) is one-tenth of the former maximum permissible annual dose for occupational exposure, on the basis of 0.3 rem/week in the most sensitive organs.*

(17) Planning for the future expansion of nuclear energy programs and the more extensive uses of radiation, requires measures intended to protect whole populations. Genetic damage is of greatest concern in this regard. The problem has been discussed by various national and international groups and tentative suggestions have been made. The Commission considered the problem at its 1956 meeting and later issued a statement in general terms.

* See footnote to paragraph 27.

* See also paragraphs 54 and 55.

However, recommendations in quantitative terms are needed in the design of power plants and other radiation installations and particularly in making plans for disposal of radioactive waste products. It is of the utmost importance in this connection to make sure that nothing is done now that may prove to be a serious hazard later, which cannot be corrected at all or will be very expensive to correct. The Commission is aware of the fact that a proper balance between risks and benefits cannot yet be made, since it requires a more quantitative appraisal of both the probable biological damage and the probable benefits than is presently possible. Furthermore, it must be realized that the factors influencing the balancing of risks and benefits will vary from country to country and that the final decision rests with each country (insofar as operations within one country do not affect other countries).

(18) The Commission wishes to point out that it is important to assign quotas of a maximum permissible genetic dose to the different modes of exposure, in order to make sure that those responsible for the control of exposure in one category do not take up a disproportionate share of the permissible total in their planning. However, at this time it is deemed best not to assign rigid quotas. As a tentative guide an illustrative apportionment is appended to paragraph 65.

(19) Briefly, the suggested limit for the genetic dose was arrived at in the following manner: Estimates made by different national and international scientific bodies indicate that a per capita gonad dose of 6–10 rems accumulated from conception to age 30 from all man-made sources, would impose a considerable burden on society due to genetic damage, but that this additional burden may be regarded as tolerable and justifiable in view of the benefits that may be expected to accrue from the expansion of the practical applications of "atomic energy". There is at present considerable uncertainty as to the magnitude of the burden (see for example the report of the United Nations Scientific Committee on the Effects of Atomic Radiation) and, therefore, it is highly desirable to keep the exposure of large populations at as low a level as practicable, with due regard to the necessity of providing additional sources of energy to meet the demands of modern society. A genetic dose of 10 rems from all man-made sources is regarded by most geneticists as the absolute maximum and all would prefer a lower dose. In some countries the genetic dose from medical procedures has been estimated to be about 4.5 rems* (see *Report of Joint Study Made by ICRP/ICRU for the U.N. Scientific Committee*). Therefore, if the limit for the genetic dose from all man-made sources were set at 6 rems, the contribution from all sources, other than medical procedures, would be limited to 1.5 rems in these countries. This would impose unacceptable restrictions on these countries. Accordingly, as a matter of practical necessity the Commission recommends that medical exposure be considered separately and that it be kept as low as is consistent with the necessary requirements of modern medical practice. The joint study of ICRP/ICRU indicates that careful attention to the protection of the gonads would result in a considerable reduction of the genetic dose due to medical procedures without impairment of their value. In view of these considerations the Commission suggests a limit of 5 rems for the genetic dose from all man-made sources of radiation and activities, except medical procedures.

(20) At the present time the contribution to the genetic dose from all man-made sources (other than medical procedures) is small. With careful planning the rate of increase can be kept under control and the ultimate value of this contribution may never reach the suggested limit of 5 rems. Since the genetic dose from medical exposure in most countries is much lower than 4.5 rems and since in those countries in which it is high efforts are being made to reduce it, the total genetic dose from all man-made sources actually received by the world population may be expected to be considerably less than 10 rems, perhaps even less than 6 rems in the foreseeable future. Furthermore, if a thermonuclear reaction can be utilized as a source of power, the problem

* See also paragraph 70.

of radiation protection may be greatly simplified.

(21) The Commission is aware that compliance with the new recommendations may entail structural changes in some existing installations and/or changes in operative procedures. Since in fact the new recommendations are more restrictive because of the greater emphasis put on the dose accumulated over a long period of time, it is not essential that such changes be made immediately, although it is obviously desirable. As a practical guide it is suggested that the transition period during which the necessary changes would be made, should not exceed 5 years.*

(22) The Commission wishes to point out again that the setting up of maximum permissible limits of occupational and non-occupational exposure (especially the latter) requires quantitative information not yet available about the risks and benefits of an expanded use of " atomic energy ". For this reason the Commission will be glad to receive factual data and suggestions from those concerned with the production or utilization of ionizing radiation, so that as much pertinent information as possible may be available to it in its future deliberations.

B. BASIC CONCEPTS†

Objectives of Radiation Protection

(23) Exposure to ionizing radiation can result in injuries that manifest themselves in the exposed individual and in his descendants: these are called somatic and genetic injuries respectively.

(24) Late somatic injuries include leukemia and other malignant diseases, impaired fertility, cataracts and shortening of life. Genetic injuries manifest themselves in the offspring of irradiated individuals, and may not be apparent for many generations. Their detrimental effect can spread throughout a population by mating of exposed individuals with other members of the population.

(25) The objectives of radiation protection are to prevent or minimize somatic injuries and to minimize the deterioration of the genetic constitution of the population.

Critical Organs and Tissues

(26) The organs and tissues of the body exhibit varying degrees of radiosensitivity, and it is therefore necessary, for purposes of protection, to consider their radiosensitivity with respect to specific functions as well as the doses they receive. When this is done, some organs and tissues assume a greater importance, according to the circumstances under which they are irradiated. They are then said to be critical.

(27) In the case of more or less uniform irradiation of the *whole body*, the critical tissues are those tissues of the body that are most radiosensitive with respect to the ability of carrying out functions essential to the body as a whole. In this report these are taken to be the blood-forming organs, the gonads, and the lenses of the eyes.‡ In previous reports the skin was listed as a critical organ in the case of whole body exposure. The presentation of the recommendations in the present report is simplified by not designating the skin as a critical organ.

(28) In the case of irradiation more or less limited to *portions* of the body, the critical tissue is that tissue most likely to be permanently damaged either because of its inherent radiosensitivity, or because of a combination of radiosensitivity and localized high dose.

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* It will be noted that this suggestion was made in 1958.

† Revised in 1962.

‡ In the 1958 Recommendations the blood-forming organs, the gonads and the lenses of the eyes were regarded as critical tissues in the case of whole body exposure. There is evidence indicating that the lens may be specially radiosensitive only to particulate radiation of high LET (e.g. neutrons having an energy of 1 MeV). On the evidence available at present the lens seems not to assume greater importance than other tissues when X-, gamma- and beta-radiations only are concerned (see paragraph 52c).

Significant Areas and Volumes

(28a) The Commission's 1955 recommendations (*Brit. J. Radiology*, Supplement 6) included a reference to the volume or area over which the dose should be averaged in the computation of maximum permissible tissue doses. This reference has not been republished in subsequent recommendations but it is recommended that the following principles should apply.

(28b) Within permissible dose ranges specified for occupational exposure, when the object of control is to reduce to a very low order of magnitude the risk of late effects (such as malignant change from an accumulated dose of radiation) it is justifiable to consider the average dose to the whole organ or tissue. This has practical advantages in that the significant volume can be taken as that of the organ or tissue under consideration. In fact, this principle has necessarily been used already in calculating permissible concentrations of radioactive nuclides in tissues.

(28c) When skin is contaminated with radioactive material, it is considered that the previous recommendation of a significant area of 1 cm^2 might be too restrictive. It is therefore recommended that the significant area in such cases be taken to be of the order of 30 cm^2. This is a practicable recommendation from the standpoint of procedures used to determine the degree of contamination of the skin.

(28d) In other cases of external exposure, especially when the distance to the source is very short or when the exposed area is very small, it would not be appropriate to recommend the dose to be assessed as the average over 30 cm^2; for these cases it is recommended that the previous practice of referring to 1 cm^2 be maintained.

Permissible Dose

(29) Any departure from the environmental conditions in which man has evolved may entail a risk of deleterious effects. It is therefore assumed that long continued exposure to ionizing radiation additional to that due to natural radiation involves some risk. However, man cannot entirely dispense with the use of ionizing radiations, and therefore the problem in practice is to limit the radiation dose to that which involves a risk that is not unacceptable to the individual and to the population at large. This is called a " permissible dose ".

(30) The permissible dose for an *individual* is that dose, accumulated over a long period of time or resulting from a single exposure, which, in the light of present knowledge, carries a negligible probability of severe somatic or genetic injuries; furthermore, it is such a dose that any effects that ensue more frequently are limited to those of a minor nature that would not be considered unacceptable by the exposed individual and by competent medical authorities.

(31) Any severe somatic injuries (e.g. leukemia) that might result from exposure of individuals to the permissible dose would be limited to an exceedingly small fraction of the exposed group; effects such as shortening of life span, which might be expected to occur more frequently, would be very slight and would likely be hidden by normal biological variations. The permissible doses can therefore be expected to produce effects that could be detectable only by statistical methods applied to large groups.

(32) The permissible dose to the gonads for the *whole population* is limited primarily by considerations with respect to genetic effects (see paragraphs 58–65).

(32a) On the basis of the criteria indicated in paragraphs 29–32, the Commission has given recommendations with regard to the *maximum* dose which, still fulfilling the above requirements, should be permitted under various circumstances. The Commission has balanced as far as possible the risk of the exposure against the benefit of the practice, and has also considered the possible danger involved in remedial actions once the exposure has occurred. This dose has been called the *maximum permissible dose.*

(32b) The basis of the Commission's recommendations is that any exposure to radiation may carry some risk. The assumption has been made that, down to the lowest levels of dose, the risk of inducing disease or disability in an individual increases with the dose accumulated by the individual, but is small even at the maximum permissible levels recommended for

occupational exposure. This assumption is supported by the limited statistics available which indicate that for radiation workers of the last generation, exposed subject to the maximum permissible levels of that time, the risks of somatic effects are comparable with or less than those of the majority of other trades and professions, and would therefore be considered as not unacceptable. The Commission similarly considered the risk of somatic effects in individuals within certain population groups, and recommended maximum permissible levels for these individuals.

(32c) With regard to genetic effects, the Commission assumed that the genetic burden to a population will be proportional to the genetic dose received by that population (see paragraph 63 of the 1958 Recommendations). The Commission therefore recommended a maximum permissible genetic dose of 5 rems,* on the basis that the resulting burden to society would be " tolerable and justifiable in view of the benefits that may be expected to accrue from the expansion of the practical application of 'atomic energy' ".

(32d) The implication of a maximum permissible dose is that it must be capable of being controlled. It is therefore clear that the Commission's recommended maximum permissible doses are appropriate for those conditions in which the levels can be controlled. However, in the case of accidents and of environmental contamination when exposures may not be subject to control, the concept of a fixed maximum permissible dose ceases to be meaningful. Instead, other considerations arise, such as the need to balance the risk from radiation against the risks of particular countermeasures. The principles upon which these risks might be assessed and balanced are still under consideration.

Dose-Rate Effects

(32e) *Somatic effects.* It has long been recognized that the effects of radiation may be dependent not only on the accumulated dose received but also on the way in which this total is fractionated and on the dose-rate at which each fraction is given. This applies particularly to radiation of low LET such as X-rays, gamma-rays and beta-radiation which are by far the commonest radiations encountered in occupational practice at the present time. It appears possible on some theoretical and experimental grounds that when either the total dose or the dose-rate is very low any effects will be directly proportional to the total dose and independent of dose-rate. This assumption is implicit in past recommendations on permissible levels and although confirmatory proof is lacking it is believed to be a reasonable basis for assessment.

(32f) *Genetic effects.* A linear dose-effect relationship unaffected by dose-rate has been generally accepted in the past for gene-mutations. Recent experimental work has shown, however, that at intermediate and higher levels of dose-rate the number of mutations produced in test-subjects may not be independent of dose-rate. Because of the importance of the genetic effect the Commission has made a special survey of recent work. This survey indicates that evidence for dependence of mutation frequency on dose-rate comes at present almost entirely from a study of seven gene-loci in spermatogonial cells and oocytes of the mouse. For insects there is not yet clear evidence of a difference in effectiveness of acute and chronic doses that cannot be ascribed to selection. No general relationship appears therefore to hold for all species.

(32g) On the basis of the above, the Commission does not at present modify its recommendations to allow for dose-rate effects in man.

Categories of Exposure

(33) These recommendations are designed to limit not only somatic but also genetic effects; it is therefore necessary to reduce as much as possible the dose to the population as a whole, as well as to the individual. In general, doses resulting from all sources of ionizing radiation should be considered in the appraisal of possible biological damage. How-

* From all sources additional to natural background plus the lowest practicable contribution from medical exposure.

ever, practical considerations make it necessary to consider separately the doses resulting from two categories of exposure, namely:

(a) Exposure to natural background radiation.

(b) Exposure resulting from medical procedures.

(34) Natural background radiation varies considerably from locality to locality and the doses it contributes to the various organs are not well known. If maximum permissible limits recommended by the Commission included background radiation, the allowable contribution from man-made sources—which are the only ones that can be controlled—would be uncertain and would have to be different for different localities. Accordingly, doses resulting from natural background radiation are excluded from all maximum permissible doses recommended in this report.

(35) In medical procedures, exposure of the patient to primary radiation is generally limited to parts of the body, but the whole body is exposed to some extent to stray radiation. The contributions to the doses in various organs and the part played in the over-all effects on the individual are practically impossible to evaluate at the present time. The Commission recognizes especially the importance of the *gonad* doses resulting from medical exposure and the attendant genetic hazard to the population. Accordingly, it recommends that the medical profession exercise great care in the use of ionizing radiation in order that the gonad dose received by individuals before the end of their reproductive periods be kept at the minimum value consistent with medical requirements. However, individual doses resulting from medical exposure are excluded from all maximum permissible doses recommended in this report.

(36) The recommendations cover the following three categories* of exposed individuals:

The first category consists of individuals who are occupationally exposed to radiation.

The second category comprises adults who work in the vicinity of controlled areas or who enter controlled areas occasionally in the course of their duties, but who are not themselves employed on work involving exposure to radiation.

The third category consists of individual members of the population at large (including persons living in the neighborhood of controlled areas).

In addition to recommending maximum permissible doses for individuals, the Commission also gives separate recommendations about the average exposure to the population as a whole, determined by exposures of the individuals within the above categories (paragraphs 58–70c).

Occupational Exposure

(37) Exposure of an *individual* who normally works in a controlled area constitutes occupational exposure. Maximum permissible doses are set for the individuals in the small portion of the population that can be occupationally exposed (paragraphs 46–52). The contribution from this group to the genetic dose to the *population* as a whole is discussed in paragraph 65.

Exposure of Adult Workers not Directly Engaged in Radiation Work

(38) Adults who work in the vicinity of controlled areas or who enter controlled areas occasionally in the course of their duties may be exposed to radiation originating in the controlled area, even if they are not themselves employed on work which ordinarily involves exposure to radiation. This category may include women of reproductive age and individuals subject to other hazards, and for these reasons the maximum permissible dose to these individuals is set lower than for persons occupationally exposed (paragraphs 53–55). The contribution from this category to the genetic dose to the whole population is discussed in paragraph 65.

Exposure of Individual Members of the Population at Large

(39) Individual members of the population at

* It should be noted that exposures within the first two categories as defined here correspond to the two classes of exposure used in the International Labour Office's Radiation Protection Convention, namely (1) Workers directly engaged in radiation work, and (2) Workers not directly engaged in radiation work.

large may be exposed to radiation originating in a controlled area or to radiation that cannot be related to any specific controlled area; e.g. exposure from environmental contamination and widely distributed radiation sources such as wrist-watches, TV-sets and various applications of radioactive materials to be expected as a result of future expansion in the atomic energy field. As such exposure is not easily controlled, it will be impossible to ensure that a recommended maximum permissible individual dose is not exceeded in any single case. Where large numbers are involved, it will not be possible to examine the habits of every individual. A reasonable procedure would be to study a sample of the group involved and to set the environmental level so that no individual in the sample receives any excessive exposure. There will always remain the possibility that someone of grossly different habits from those in the observed sample may receive a higher dose than the maximum in the sample.

(40) In order to facilitate planning for the anticipated increased uses of nuclear energy and other sources of radiation, it is desirable at this time to recommend a maximum for the genetic dose to the *population* (paragraph 64); this maximum will determine what average gonad exposure could be allowed. Part of the recommended maximum genetic dose will have to be used for occupational exposure, for exposure of adult workers not directly engaged in radiation work, and for medical exposure. The proper apportionment for exposure of the population at large must allow for both internal and external exposure (paragraph 65).

Medical Exposure

(41) No recommendations are given with regard to the dose to the individual from medical exposure. (The contribution of medical exposure to the genetic dose is discussed in paragraphs 69–70.)

Reduction in Maximum Permissible Dose

(42) The 1958 recommendations were introduced partly with the intention of limiting the genetically significant radiation exposure (see paragraph 63) of the population, and partly to limit the probability of somatic injury by reducing the lifetime dose. This reduction does not result from positive evidence of damage due to the use of the earlier permissible dose levels, but rather is based on the concept that biological recovery may be minimal at such low dose levels.

Time Interval over which Dose is to be Assessed

(43) The maximum permissible weekly doses recommended by the Commission in 1950 were replaced in 1958 by limits for the doses received over longer periods of time (paragraphs 47–49). In the case of occupational exposure the maximum permissible dose that may be accumulated at a certain time depends on the age of the worker. The dose to individuals in the population at large, or in special groups other than occupational, may be accumulated at a rate that is determined by a maximum permissible annual dose. The genetic dose to the whole population is assessed over the period between conception of the individual and conception of each child of the individual. (See paragraph 63 for method of evaluation.)

(44) These extended periods of time allow for some flexibility in the way in which radiation exposure may be received, and at the same time provide what is considered to be adequate protection for each group of the population.

C. MAXIMUM PERMISSIBLE DOSES*

GENERAL

(45) It is emphasized that the maximum permissible doses recommended in this section are *maximum* values; the Commission recommends that all doses be kept as low as practicable, and that any unnecessary exposure be avoided.

* Revised in 1962.

EXPOSURE OF INDIVIDUALS

Occupational Exposure

(46) In any organ or tissue, the *total* dose due to occupational exposure shall comprise the dose contributed by external sources during working hours and the dose contributed by internal sources taken into the body during working hours. It shall not include any medical exposure or exposure to natural radiation. The Commission wishes to emphasize that " medical exposure " refers to the exposure of *patients* that is necessary for medical purposes and *not* to the exposure of the personnel conducting such procedure.

Exposure of the Gonads and the Blood-forming Organs

(47) The maximum permissible total dose accumulated in the gonads and the blood-forming organs at any age over 18 years shall be governed by the relation.

$$D = 5(N - 18)$$

where D is tissue dose in rems* and N is age in years.

(48) For a person who is occupationally exposed at a constant rate from age 18 years, the formula implies a maximum weekly dose of 0.1 rem. It is recommended that this value be used for purposes of planning and design.

Rate of Dose Accumulation

(49) To the extent the formula permits, an occupationally exposed person may accumulate the maximum permissible dose at a rate not in excess of 3 rems during any period of 13 consecutive weeks (i.e. in no 13 consecutive weeks shall the dose exceed 3 rems).† If necessary, the 3 rems may be received as a single dose, but as the scientific knowledge of the biological effects of differing dose-rates is scant, single doses of the order of 3 rems should be avoided as far as practicable.

(49a) *Exposure of women of reproductive age.* The recommendation for dose accumulation at rates up to 3 rems per quarter should not apply in circumstances involving abdominal exposure of women of reproductive age. Women of reproductive age should be occupationally employed only under conditions where the exposure of the abdomen is limited to 1.3 rems in a 13 week period, corresponding to 5 rems per year delivered at an even rate. Under these conditions the dose to an embryo during the first two months of pregnancy would normally be less than 1 rem, a dose which the Commission considers to be acceptable.

(49b) *Exposure of pregnant women.* When a pregnancy has been diagnosed, arrangements should be made to ensure that the exposure of the woman be such that the average dose to her fetus during the remaining period of the pregnancy does not exceed 1 rem. Under conditions in which the fetal dose may approximate to that received by the woman, for example when the abdomen is exposed to penetrating radiation, this recommendation will normally be met if the woman is not exposed at rates greater than those applicable to adult workers not directly engaged in radiation work, since such workers may not be exposed at rates greater than 1.5 rems per year (see paragraph 54).

(49c) Under conditions in which the fetal dose will be considerably less than that received by the woman, as for example when working with diagnostic X-ray equipment of 150 kV or less, or where the abdomen is protected from or not exposed to the radiation, the recommendation may be satisfied by continuing occupational exposure of the woman at a rate not exceeding 1.3 rems per 13 weeks.

*Application to Special Cases**

(50) Setting permissible limits of exposure in terms of the dose accumulated up to a given age introduces certain practical complications. Thus, some workers (previously exposed at levels within the then permissible limits) may have already accumulated a dose in excess of the maximum permitted by the formula. There

* See earlier discussion of *RBE* and *QF*.

† A calendar 13 week period starting at any chosen date may be used instead of a period of 13 consecutive weeks if there is no reason to suppose that doses are being accumulated at grossly irregular rates.

* Paragraphs 50 to 51c are reproduced from the 1958 Recommendations of the Commission.

are also special cases in which exceptions in the application of the formula may be desirable for practical reasons and are justifiable within the context of paragraph 42. The following recommendations are intended to provide guidance on administrative policy, which may well vary according to circumstances at the local level. (It should be noted that this situation will obtain only during a relatively short transition period.)

(51a) *Previous exposure history unknown.* When the previous occupational exposure history of an individual is not definitely known, it shall be assumed that he has already received the full quota permitted by the formula.

(51b) *Persons exposed in accordance with the former maximum permissible weekly dose.* Persons who were exposed in accordance with the former maximum permissible weekly dose of 0.3 rem and who have accumulated a dose higher than that permitted by the formula, should not be exposed at a rate higher than 5 rems in any one year, until the accumulated dose at a subsequent time is lower than that permitted by the formula.

(51c) *Persons starting work at an age of less than 18 years.* When a person begins to be occupationally exposed at an age of less than 18 years, the dose shall not exceed 5 rems in any one year under age 18, and the dose accumulated to age 30 shall not exceed 60 rems. (The minimum age at which occupational exposure is legally permitted is lower than 18 years in some countries.)

(51d) *Accidental high exposure.* An accidental high exposure that occurs *only once in a lifetime* and contributes no more than 25 rems shall be added to the occupational dose accumulated up to the time of the accident. If the sum then exceeds the maximum value permitted by the formula, the excess need not be included in future calculations of the person's accumulated dose. Accidental exposure to doses higher than 25 rems must be regarded as being potentially serious, and shall be referred to competent medical authorities for appropriate remedial action and recommendations on subsequent occupational exposure. This is intended as an administrative guide to permit the continuation of work with radiation, following a bona fide accident ("once in a lifetime"), in cases in which interruption of such work, or curtailment of exposure, would handicap the individual in the pursuit of his career.

(51e) *Emergency exposure.* Emergency work involving exposure above permissible limits shall be planned on the basis that the individual will not receive a dose in excess of 12 rems. This shall be added to the occupational dose accumulated up to the time of the emergency exposure. If the sum then exceeds the maximum value permitted by the formula, the excess shall be made up by lowering the subsequent exposure rate so that within a period not exceeding 5 years, the accumulated dose will conform with the limit set by the formula. Women of reproductive age shall not be subjected to such emergency exposure.

Exposure of Single Organs other than the Gonads and the Blood-forming Organs

(52) For exposure that is essentially restricted to portions or single organs of the body, with the exception of the gonads and the blood-forming organs, a higher dose than the one derived from the formula $D = 5(N - 18)$ is permitted. The following recommendations are made.

(52a) *A maximum dose of 8 rems/13 weeks for the skin, thyroid and bone.** The maximum dose in the skin, thyroid and bone, accumulated over any 13 consecutive weeks, shall not exceed 8 rems. This recommendation applies to all exposure of the skin, except the skin of the hands and forearms, feet and ankles (see paragraph 52b). As the 8 rems are derived from an average of 0.6 rem/week, the annual dose for a 50 week year is limited to 30 rems.

(52b) *A maximum dose of 20 rems/13 weeks for the hands and forearms, feet and ankles.* In the case of exposure of the hands and forearms, feet and ankles, the maximum dose accumulated over any 13 consecutive weeks shall not exceed 20 rems. This recommendation applies to all tissues of the above-mentioned extremities. As the 20 rems are derived from an average of

* The dose to bone is based on a body-burden of 0.1 μc of Ra^{226} (see Report of Committee II, ICRP Publication 2).

1.5 rems/week, the annual dose for a 50 week year is limited to 75 rems.

(52c) *A maximum dose of 4 rems/13 weeks for limited exposure of internal organs* other than the thyroid, the gonads and the blood-forming organs.* In the case of internal organs, limited exposure originates almost exclusively from radioisotopes within the body. As most planning of release of radioactive isotopes to the air and water supplies in controlled areas is made under conditions where occupational groups rather than single individuals are exposed, a formula corresponding to the one given in paragraph 47 cannot in general be applied to internal exposure. An average of 0.3 rem/week in the organ of interest (with some exceptions noted in the report of Committee II) is expected to be maintained under equilibrium conditions if the concentration in air *or* water of the relevant isotope is kept at levels given in the tables in the report of Committee II. Variations of the dose-rate will occur in practice, and are permissible, provided that the dose accumulated over any 13 consecutive weeks does not exceed 4 rems. As this maximum is derived from a weekly average of 0.3 rem, the annual dose for a 50 week year is limited to 15 rems. In the case of irradiation of the lens of the eye with particulate radiation of high LET (e.g. neutrons having an energy of 1 MeV) a special *QF* of 30 shall be used, instead of the usual value of 10.

(52d) *Whole body exposure from uptake of several radioisotopes.* When the radioactive isotopes in a mixture are taken up by several organs and the resultant tissue doses in such organs are of comparable magnitude, the combined exposure is considered to constitute essentially whole body exposure. Accordingly, the permissible levels of exposure will be those applicable to the gonads and the blood-forming organs.

(52e) *Short-term exposures to radioactive materials.* One or more short-term exposures to radioactive materials within a period of 13 consecutive weeks is considered acceptable if the total *intake* of radioactive material during this period does not exceed the cumulative intake allowed when exposure occurs for 13 weeks at the maximum levels (MPC values) for occupational exposure given in the Report of Committee II (ICRP Publication 2). If significant exposure to external sources occurs concurrently, the quarterly intake referred to above should be estimated to make allowance for the dose equivalent delivered by external sources (ICRP Publication 2, page 24). The 50 year integrated dose to the critical organ from such an intake will not exceed 1.3 rems for the whole body, blood-forming organs or gonads, 8 rems for skin, thyroid and bone,* and 4 rems for other organs.

(52f) *Chemical toxicity.* Because of the toxicity of natural uranium, U^{238}, U^{236}, or U^{235} in soluble form in amounts permitted according to the above on the basis of radiological protection, the inhalation of uranium of any isotopic composition should not exceed 2.5 milligrams of soluble uranium in one day, or the ingestion averaged over 2 days should not exceed 150 milligrams of soluble uranium.† For insoluble forms of uranium, maximum intake shall be limited by the same rule that applies to other radioactive materials set forth above. Because of the low specific activity of certain other radioactive materials with very long radioactive half-lives (e.g. Rb^{87}, In^{115}, Nd^{144}, Sm^{147}, Re^{187}, etc.), the mass or chemical toxicity will in general determine maximum rates of intake. Similar considerations will apply also to the values given in Table 1 of ICRP Publication 2.

(52g) *Accidental high exposure to radioactive materials.* In the case of an accidental high exposure to radioactive materials where the total intake of radioactive material exceeds the amount that would result from intake for 1 year at the maximum levels for occupational exposure

* Including the lens of the eye.

* The dose to bone is based on a body-burden of 0.1 μc of Ra^{226} (see Report of Committee II, ICRP Publication 2).

† This restriction on the ingestion of soluble forms of uranium revises the maximum permissible concentration recommended in Table 1 of ICRP Publication 2 for the continuous ingestion of drinking water. The new values of MPC for uranium that result from taking into account the chemical toxicity of uranium are given in Part 5 of the present report (ICRP Publication 6).

to such radioactive materials given in the Report of Committee II (ICRP Publication 2), an estimate of the intake resulting from the exposure shall be entered on the individual's record and he shall be referred to competent medical authorities for appropriate action.

(52h) *Emergency work involving exposure to radioactive materials.* Emergency work involving exposure to radioactive materials at levels above the normal maximum permissible concentrations shall be planned on the basis that the total intake of radioactive material during the emergency period should not exceed the cumulative intake that would result from exposure for 1 year at the maximum levels (MPC values) for occupational exposure to such radioactive materials given in the Report of Committee II (ICRP Publication 2). If significant exposure to external sources might be expected to occur concurrently, the annual intake referred to above should be estimated to make allowance for the dose equivalent delivered by the external sources (ICRP Publication 2, page 24). The 50 year integrated dose to the critical organ from such an intake will not exceed 5 rems for the whole body, blood-forming organs or gonads, 30 rems for skin, thyroid and bone,* and 15 rems for other organs. When such an exposure has occurred, an estimate of the intake shall be entered in the individual's record, and action shall be taken appropriate to paragraphs 86 and 86a.

Adult Workers not Directly Engaged in Radiation Work

(53) In any organ or tissue, the total maximum permissible individual dose shall consist of the sum of the doses contributed by both external and internal sources. It shall not include any medical exposure or exposure to natural radiation.

(54) For adult workers not directly engaged in radiation work (see paragraph 36) the total annual dose, including contributions from external and internal sources, to the gonads and the blood-forming organs, shall not exceed 1.5 rems, nor shall the contribution from a mixture of isotopes whose combined exposure constitutes essentially whole body exposure, make the total annual dose exceed 1.5 rems.

(55) The annual dose to all other organs and tissues, and to the hands and forearms, feet and ankles, shall be limited to one-tenth of the corresponding annual occupational doses.

Individual Members of the Population at Large

(56) In any organ or tissue the total maximum permissible individual dose shall consist of the sum of the doses contributed by both external and internal sources. It shall not include any medical exposure or exposure to natural radiation.

(57) The population at large contains children, for whom it is considered that a lower dose to the gonads and the blood-forming organs should apply. The maximum total dose limit for individuals in the population at large shall be 0.5 rem per year to the gonads and the blood-forming organs, nor shall the contribution from a mixture of isotopes whose combined exposure constitutes essentially whole body exposure make the total annual dose exceed 0.5 rem.

(57a) The annual dose to all other organs and tissues and to the hands and forearms, feet and ankles, shall be limited to one-tenth of the corresponding annual occupational doses. This recommendation applies to exposures for which control can be exercised. In the case of accidents and of environmental radiation beyond regular control, special considerations arise (see the above discussion on permissible dose).

EXPOSURE OF POPULATION†

General

(58) Proper planning for nuclear power programs and other peaceful uses of atomic energy on a large scale requires a limitation of the exposure of whole populations, partly by limiting the individual doses and partly by limiting the number of persons exposed.

(59) This limitation necessarily involves a

* The dose to bone is based on a body-burden of 0.1 μc of Ra^{226} (see Report of Committee II, ICRP Publication 2).

† This section deals with exposures averaged over whole populations.

compromise between deleterious effects and social benefits. Consideration of genetic effects plays a major role in its evaluation. The problem has been discussed extensively in recent years and suggestions have been made by different national bodies. The Commission is aware of the fact that a proper balance between risks and benefits cannot yet be made, since it requires a more quantitative appraisal of the probable biological damage and the probable benefits than is presently possible. Furthermore, it must be realized that the factors influencing the balancing of risks and benefits will vary from country to country and that the final decision rests with each country.

(60) Because of the urgent need for guidance in this regard, the Commission in its 1958 Recommendations suggested an interim ceiling for the exposure of the whole population. The proposed level is essentially in accordance with suggestions by other scientific groups that have studied the problem and tried to evaluate the possible biological effects. It is felt that this level provides reasonable latitude for the expansion of atomic energy programs in the foreseeable future. It should be emphasized that the limit may not in fact represent the proper balance between possible harm and probable benefit, for reasons already mentioned.

(61) On the assumption that the genetic effects are linearly related to the gonad dose and provided that no threshold dose exists, it is possible to define a population dose average that is relevant to the assessment of genetic injury to the whole population (paragraphs 62–63). In the case of somatic effects no such dose can easily be defined although the annual per capita dose to certain tissues or to the whole body may be relevant on the assumption of a non-threshold, linear dose-effect relation.

Genetic Dose

Assessment of Genetic Dose

(62) The genetic dose to a population is the dose which, if it were received by each person from conception to the mean age of childbearing, would result in the same genetic burden to the whole population as do the actual doses received by the individuals. A permissible genetic dose is that dose, which if it were received by each person from conception to the mean age of childbearing, would result in an acceptable burden to the whole population.

(63) The genetic dose to a population can be assessed as the annual genetically significant dose multiplied by the mean age of childbearing, which for the purpose of these recommendations is taken to be 30 years. The annual genetically significant dose to a population is the average of the individual gonad doses, each weighted for the expected number of children conceived subsequent to the exposure.

Maximum Permissible Genetic Dose

(64) It is suggested that the genetic dose (see paragraph 63) to the whole population from all sources additional to the natural background should not exceed 5 rems plus the lowest practicable contribution from medical exposure. The background is excluded from the suggested value because it varies considerably from country to country. The contribution from medical exposure is considered separately for the same reason and also because the subject is being studied for the purpose of limiting such exposure to the minimum value consistent with medical requirements.

Apportionment of Genetic Dose

(65) The suggested maximum genetic dose of 5 rems in addition to the dose from medical procedures and natural background must not be used up by one single type of exposure. The proper apportionment of the total will depend upon circumstances which may vary from country to country, and the decision should therefore be made by national authorities.

Addendum to Paragraph 65

(a) *Illustrative apportionment.* The Commission does not wish to make any firm recommendations as to the apportionment of the genetic dose of 5 rems but, for guidance, gives the following apportionment as an illustration:

(A)	Occupational exposure	1.0 rem
(B)	Exposure of adult workers not directly engaged in radiation work	0.5 rem

(C) Exposure of the population at large 2.0 rem
Reserve .. .. 1.5 rem

(b) *Fractions of population.* Assuming that the ratio of the total population to the reproductive population is the same in all groups, the largest fraction (ε) of the whole population that can be exposed to an average annual dose D_1^i is given by the equation:

$$\varepsilon.30.D_1^i = D_{30}^i$$

where D_{30}^i is the apportionment of the genetic dose to the ith exposure group, and the average annual dose within the group can be expressed as a fraction of the maximum permissible individual annual dose; i.e. $D_1^i = F_1 D_1^i$.

(c) *Occupational exposure.* Assigning 1.0 rem to occupational exposure would mean that 0.7 per cent of the whole population could accumulate the maximum permissible occupational gonad dose of 60 rems by age 30. It is very unlikely that such a figure will be approached in the foreseeable future. At the present time, the number of persons occupationally exposed in technologically developed countries is about 0.1–0.2 per cent of the population, and most of these persons receive doses which are considerably less than the maximum permissible doses.

(d) *Exposure of adult workers not directly engaged in radiation work.* An apportionment of 0.5 rem for the exposure of adult workers not directly engaged in radiation work would imply that about 1 per cent of the population could receive the maximum permissible individual annual gonad doses for these individuals. The allowable size of this group varies inversely with the average dose within the group. Thus, if this dose were only 10 per cent of the maximum individual doses, the group could amount to 10 per cent of the whole population, which is larger than is likely to occur.

(e) *Exposure of the population at large.* The apportionment of 2.0 rems (with a long-term reserve of 1.5 rems for possible eventualities) for the genetic exposure of the population at large is intended for planning purposes in the development of nuclear energy programs (with the associated waste disposal problems) and more extensive uses of radiation sources. In the case of internal exposure, the radioisotopes of interest are those that contribute to the gonad dose directly (by local concentration) or indirectly (by radiation produced elsewhere in the body). In either case the maximum permissible concentrations in air and water of these isotopes recommended by Committee II for continuous occupational exposure ("168 hour week") are based on an average yearly dose of 5 rems in the gonads or the whole body. If for these isotopes the average concentrations in public air and water supplies are lower than the values recommended for continuous occupational exposure by a factor of 1/100, the genetic dose to the population would amount to 1.5 rems (5 × 1/100 rems/year in the gonads × 30 years = 1.5 rems). In this case the contribution from external sources should be limited to 0.5 rem in order not to exceed the total of 2 rems.

Somatic Dose

(66) No specific recommendations are made at this time as to the maximum permissible "somatically" relevant dose to the population. However, it is expected that the maximum permissible limits of the *individual* total doses recommended in paragraphs 46–57a will keep the average dose in any tissue at such a level that the injuries that could possibly occur in a population would be well within acceptable limits (see paragraph 31).

(67) In the case of external exposure of the whole body to penetrating radiation the restriction imposed by the genetic dose to the population automatically reduces the doses to internal organs below the *individual* maximum permissible annual doses recommended in paragraphs 46–57a. Thus the probability of somatic injury in these organs is considerably lower than indicated in paragraph 66. The same thing applies to internal exposure resulting from radioisotopes that directly or indirectly contribute to the gonad dose of a population (see addendum to paragraph 65).

(68) There remain for further consideration those isotopes that concentrate in specific organs (other than the gonads). In view of the existing uncertainty as to the dose-effect relationships for somatic effects, it is suggested that for planning purposes the average concentrations of such isotopes, or mixtures thereof, in air or water, applicable to the population at large, should not exceed one-thirtieth of the MPC values for continuous

occupational exposure given in the report of Committee II.*

MEDICAL EXPOSURE

Radiological Examinations of Women of Reproductive Age

(69) The Commission wishes to call attention to reports of embryonic and fetal sensitivity to ionizing radiation and to emphasize that the possibility of pregnancy must be taken into account by the attending physician when deciding on radiological examinations that involve the lower abdomen and pelvis of women of reproductive age. The Commission also wishes to point out that the 10-day interval following the onset of menstruation is the only time when it is virtually certain that women of such age are not pregnant. Therefore, it is recommended that all radiological examinations of the lower abdomen and pelvis of women of reproductive age, that are not of importance in connection with the immediate illness of the patient, be limited in time to this period when pregnancy is improbable. The examinations that should be delayed to await the onset of the next menstruation are those that could without detriment be delayed till the conclusion of a pregnancy or at least until its latter half.

Apportionment of Total Genetic Dose—Medical Exposure

(70a) In the 1958 Recommendations (paragraph 70) the Commission referred to the upper limit of the estimates of the annual genetically significant dose from medical exposure, and noted that the highest levels could be reduced significantly by careful attention to techniques.

(70b) More recent estimates of the genetic dose from medical exposure, described in the 1962 Report of UNSCEAR,† indicate that the actual dose may be considerably less than the highest levels referred to above. In addition, the 1962 UNSCEAR Report referred to estimates, which have been made in two countries, of the extent by which a reduction in dose could be achieved without loss of necessary medical information.‡

(70c) Paragraph 70 of the 1958 Recommendations concluded: "A certain allowance for medical exposure of populations must be made and may be made in the near future as the subject is being studied for the purpose of limiting such exposure to the minimum value consistent with medical requirements". It is clear that the permissible dose will depend upon the value of the medical benefit to be derived, and future extensions in the use of radiological methods may confer greater benefit from their application than detriment from the necessary associated exposure to radiation. At the present time the Commission has decided to maintain its policy of not making numerical recommendations with regard to the appropriate genetic dose from medical exposures.

D. GENERAL PRINCIPLES REGARDING WORKING CONDITIONS§

RESPONSIBILITY

(70d) The owner or the person in charge of a controlled area shall be responsible for the working conditions and for the instruction of all persons working in the area regarding radiation hazards and methods of control. He shall be responsible for maintaining radiation levels outside the controlled area resulting from

* The basis for the limits of permissible exposure of populations to man-made sources of ionizing radiations is the dose received by the various organs of the body and not the MPC values, or other criteria by which the dose is controlled. Nevertheless, for planning purposes some guidance as given in paragraph 68 must be available. The word "average" in paragraph 68 refers to the concentration of radioactive nuclides, averaged over a year, in the total intake to the average person of the population. (See also page 14 concerning MPC values and dose in the case of children.)

† Estimates of the annual genetically significant dose from X-ray diagnosis in 14 countries ranged from 6 to 60 mrem.

‡ Ministry of Health, Department of Health for Scotland, Radiological Hazards to Patients. Second Report of the Committee. HMSO (1960).

Larsson, L-E. *Acta Radiologica*, Supplement 157: 7–127 (1958).

§ Reproduced from the Commission's 1958 Recommendations with the addition of paragraphs 84a and 86a.

operations within the area so that exposures do not exceed the maximum permissible doses recommended in paragraphs 53–57a.

(71) A controlled area shall be established where persons occupationally exposed could receive doses in excess of 1.5 rems/year.

(72) A controlled area is an area in which the exposure of personnel to radiation or radioactive material is under the supervision of a radiation protection officer.

(73) A radiation protection officer is one who has the knowledge and responsibility to apply appropriate radiation protection regulations. He may be the owner or the person in charge of the controlled area or he may be a technically competent person appointed by the above.

(74) A qualified expert (or health physicist) is a person having the knowledge and training needed to measure ionizing radiations and to advise regarding radiation protection. The qualification should be of the type specified by a National Committee.

Radiation Surveys and Monitoring

Surveys Prior to Use of Controlled Areas

(76) In those instances where the operations in a controlled area may disturb or alter significantly the environment with respect to radiation hazards, adequate surveys should be made of the radioactivity of the air, soil and water prior to the start of operations. This will provide a base line from which to judge the adequacy of radiation controls within the area.

(77) During and after installation, appropriate radiation surveys shall be made to ensure that the pertinent recommendations will be complied with when routine operations commence. Routine operations shall be deferred until such compliance is assured.

(78) When additional operations are planned in the area, a thorough survey should be made of the background radiation prior to the start of the new operations. This will aid in the identification of the operation responsible for any increase of the background radiation or the contamination in the area.

Routine Surveys and Monitoring

(79) Radiation surveys shall be made regularly, at a frequency dictated by the operations within the area, to determine the adequacy of safety procedures. This should include checks of the facilities, equipment (radiation warning devices, radiation shields, hoods, respirators, ventilating system, etc.), and working techniques. When there is any reasonable probability of a radiation hazard existing, the vicinity of the controlled area should also be surveyed.

Special Surveys

(80) Specific and detailed recommendations regarding radiation surveys applicable to some special cases are given in the Reports of the Committees of ICRP.

Health Surveillance

Pre-employment Examination

(81) All new personnel in radiation work shall have a pre-employment medical examination. Notes should be made of the family history, of the previous occupational history, and of previous X-ray diagnostic examination or radiation therapy. The examination shall include a complete blood count, with determination of erythrocyte and leukocyte levels and a differential white cell count. It should be recognized that the examination is directed toward determining the " normal " condition of the worker at the time of employment, and toward noting any abnormalities that might later be confused with radiation damage.

(82) In cases where there has been previous occupational exposure, the total accumulated dose shall be recorded (see paragraphs 47–51) and any appropriate additional medical examinations performed. These should include ophthalmological examinations, with particular reference to changes in the lens, in cases of exposure to neutrons and to heavy particles, and examinations of skin and nails in the case of partial external irradiation and external contamination.

Routine Medical Examinations

(83) Medical examinations should be per-

formed at a frequency depending upon the conditions of the occupational exposure. Blood counts, although they are a part of a medical examination, are not to be considered as a method of radiation monitoring.

(84) Persons occupationally exposed to neutrons and to heavy particles of significant penetration should have ophthalmological examinations, with particular reference to changes in the lens. The frequency of the examination will depend upon the conditions of exposure.

Occupational Working Hours and Length of Vacation

(84a) The Commission considers that with the present maximum permissible exposure levels no special treatment of radiation workers with respect to working hours and length of vacation is needed.

Personnel Monitoring

External Radiation

(85) Doses received as a result of occupational exposures shall be systematically checked with appropriate instruments to ensure that the maximum permissible doses are not exceeded and to make it possible to keep individual cumulative dose records.

Internal Radiation

(86) Tests should be performed to estimate the total body-burden for workers who deal with unsealed radioactive isotopes that may give rise to levels of ingestion or inhalation in excess of the maximum permissible concentrations. Such tests should also be performed where radioisotopes may enter the body through the skin or through skin punctures and open wounds. These tests may require the monitoring of breath and and excreta, and the direct determination of the body-burden by means of a total body monitor, according to circumstances. The radiation doses delivered to the appropriate organs or tissues should be calculated and noted on the personal record, and the permitted doses of external radiation should be adjusted to allow for the " internal " doses.

Addition of Doses from External and Internal Exposures

(86a) The Commission has considered the difficulty of making proper allowance for the addition of doses from penetrating external exposure and from internal exposure *in the case of long-lived bone-seeking isotopes*, in view of the use for them of the " n " factor. For these radionuclides the Commission recommends that

(i) if the estimated body-burden is less than one-half of the maximum permissible, no consequential restriction of external radiation exposure need be applied;

(ii) if the estimated body-burden is greater than one-half but less than the maximum permissible, the total body exposure to penetrating external radiation shall be limited to not more than 1.5 rems in any year; and if A years is the age of the individual when the body-burden was first found to exceed one-half the maximum permissible, then the total accumulated dose from such future exposure beyond age A shall not exceed $1.5(N - A)$ rems where N is the current age of the individual; if, however, at age B the body-burden is found to have dropped to less than one-half the maximum permissible value, the accumulated dose from future external total body exposure beyond age B shall not exceed $5(N - B)$ rems.

(iii) if the estimated body-burden equals or exceeds the maximum permissible, no occupational exposure to penetrating external radiation is permissible.

Radiation Warning Devices

(87) An appropriate form of warning shall be provided to indicate the existence of a radiation hazard, even if the hazard is of a temporary nature only. In the latter case the warning device should be removed when the hazard no longer exists.

5. 1962 SUPPLEMENT
TO
REPORT OF COMMITTEE II
ON PERMISSIBLE DOSE FOR INTERNAL RADIATION
(ICRP PUBLICATION 2)

Tables:

A. Distribution of Spontaneous Fission Energy;

1962 Supplement to ICRP Publication 2, Table 1 (Maximum permissible body-burdens and maximum permissible concentrations of radionuclides in air and water for occupational exposure);

1962 Supplement to ICRP Publication 2, Table 5 (Effective Energies);

1962 Supplement to ICRP Publication 2, Table 5a (Effective Energies for Chains);

1962 Supplement to ICRP Publication 2, Table 12 (Biological and related physical constants).

Errata to Report of Committee II on Permissible Dose for Internal Radiation (1959).

COMMENTS AND ASSUMPTIONS APPLYING TO THE 1962 SUPPLEMENT TO THE REPORT OF COMMITTEE II ON PERMISSIBLE DOSE FOR INTERNAL RADIATION (1959)

Tissue Distribution of Cs^{137}

More recent and more extensive data on the distribution of Cs^{137} and stable caesium in various body tissues have indicated that the distribution is essentially homogeneous. Although the newer data do not significantly alter the MPC values, they lower the estimate of the associated dose to bone and to the blood-forming organs.

Recommendations on MPC Values for Sr^{90}

Since the publication of the Report of Committee II (ICRP Publication 2) very extensive data on the human metabolism of strontium and calcium have become available, but there has been little new information on the hazard associated with a sustained maximum permissible body-burden of Sr^{90}. The Commission is, accordingly, not changing its recommendations concerning the permissible *body-burden* of Sr^{90} at this time. However, the Commission considers that the metabolic data provide a sounder basis for estimation of *MPC values* for Sr^{90}, with bone as the critical organ, than does the exponential model used previously in the recommendations. Extensive experimental data indicate that the strontium–calcium ratio of mineral derived from diet in newly formed bone is about 0.25 of the corresponding ratio in the normal human diet. Data are also available on the average concentrations of stable strontium and stable calcium in normal human diet and bone of large populations. Both sets of data indicate that an $(MPC)_w$ value of about 4×10^{-6} $\mu c/cm^3$ and an $(MPC)_a$ value of about 4×10^{-10} $\mu c/cm^3$ for occupational exposure (168-hour week) would correspond to the maximum permissible body-burden of 2 μc with bone as the critical organ. These values do not differ markedly from those resulting from the use of a power function model for retention of strontium as given in the Appendix of the Committee II Report (ICRP Publication 2). Thus three largely independent methods of estimation support the above MPC values, and therefore the Commission now recommends that these values be used as the basis for limiting occupational exposure to Sr^{90} with bone as the critical organ. The $(MPC)_w$ and $(MPC)_a$ values for occupational exposure (40-hour week) with bone as the critical organ are 1×10^{-5} $\mu c/cm^3$ and 1×10^{-9} $\mu c/cm^3$, respectively.

The MPC and body-burden values with total body as the organ of reference also have been revised on the basis of the above model. Similar considerations apply to the MPC values for Sr^{89} but result in values which do not differ significantly from those in the Report of Committee II (ICRP Publication 2).

Statement on $(MPC)_a$ for Rn^{222}

The Commission assumes that the biological hazard to man associated with a continued exposure to high concentrations of Rn^{222} and daughters in inspired air is carcinoma of the bronchus. It is not at present aware of direct biological evidence on which to base a maximum permissible concentration of these radionuclides in air for continuous exposure. In 1959 it therefore made use of the experimental physical evidence available on the deposition in the bronchus of the daughters of Rn^{222} present in inspired air; this evidence was used to

calculate a maximum permissible concentration of Rn^{222} and its daughters in inspired air; that is, the concentration that would deliver to bronchial mucosa a dose of 15 rems per year. Since the radiation dose-rate to bronchus that results from breathing a mixture of Rn^{222} and its daughter products depends on the fraction of RaA daughter-atoms unattached to condensation nuclei, the maximum permissible concentration of Rn^{222} and daughters depends on the magnitude of this fraction in the particular atmosphere considered. The recommendations of the Commission allow for appropriate adjustments of the MPC value for Rn^{222} and its daughter products, by taking into account the values of this fraction in particular atmospheres. The value of MPC for Rn^{222} and daughters quoted in Table 1 of the Report of Committee II (ICRP Publication 2) is based upon an assumption that this fraction is 10 per cent. The value of this fraction may differ in particular circumstances, and the implications of such differences are discussed on page 23 of the Report of Committee II (ICRP Publication 2). The Commission is not aware of new evidence that would lead it to revise this maximum permissible concentration in air for exposure to Rn^{222} and daughters.

Chemical Toxicity

Because of the chemical toxicity of natural uranium, U^{238}, U^{236}, or U^{235} in soluble form in amounts permitted according to the above on the basis of radiological protection, the inhalation of uranium of any isotopic composition should not exceed 2.5 milligrams of soluble uranium in one day, or the ingestion averaged over 2 days should not exceed 150 milligrams of soluble uranium.* For insoluble forms of uranium, maximum intake shall be limited by the same rule that applies to other radioactive materials set forth above. Because of the low specific activity of certain other radioactive materials with very long radioactive half-lives (e.g. Rb^{87}, In^{115}, Nd^{144}, Sm^{147}, Re^{187}, etc.), the mass or chemical toxicity will in general determine maximum rates of intake. Similar considerations will apply also to the values given in Table 1 of ICRP Publication 2.

Transuranic Radionuclides

Values listed in the tables were calculated according to the equations and assumptions in the Report of Committee II on Permissible Dose for Internal Radiation, 1959 (ICRP Publication 2). The format of the tables is the same as that in the tables of ICRP Publication 2.

Biological data used in the computations were taken from Table 12 of ICRP Publication 2 where these data were given, i.e. for Pu, Am, Cm, Bk, and Cf. Where values were needed for isotopes not listed in that table, they were computed by the equations indicated there in the column headings. For elements Es and Fm, which do not appear in Table 12, Pu bone values were used to estimate the necessary parameters for the different isotopes, as was done in Table 12 for Bk and Cf.

Physical data for determining radioactive half-lives, type and mode of decay, and energy quantities and intensities were taken principally from references (1) and (2) of this Supplement.

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* This restriction on the ingestion of soluble forms of uranium revises the maximum permissible concentration recommended in Table 1 of ICRP Publication 2 for the continuous ingestion of drinking water. The new values of MPC for uranium that result from taking into account the chemical toxicity of uranium are given on pp. 44–45 of the present report (ICRP Publication 6).

One problem arose with the new group of radionuclides that was not encountered in the previous group. A survey of the pertinent literature revealed that the quantity and distribution of spontaneous fission energy for most of the radionuclides involved are not precisely known as yet. However, it has been shown both theoretically and experimentally[3] that the energy release in spontaneous fission is similar to the energy release in the neutron-induced fission of U^{235}. The approximate distribution[4] of neutron-induced fission energy is:

(1)	Kinetic energy of fission fragments	168 ± 5 MeV
(2)	Instantaneous gamma-ray energy	5 ± 1 MeV
(3)	Kinetic energy of fission neutrons	5 ± 0.5 MeV
(4)	Beta-particles from fission products	7 ± 1 MeV
(5)	Gamma-rays from fission products	6 ± 1 MeV
(6)	Neutrinos	~ 10
	Total fission energy	201 ± 6 MeV

The energy in groups (1), (2), and (3) is released at the time of fission (considering for this purpose the time of the delayed neutrons is negligible), while that in groups (4) and (5) is set free gradually as the fission products decay. Since neutrinos do not interact appreciably with matter, the energy from that source can be neglected.

The calculations involving spontaneous fission in the present list made use of data contained in Table A of this Supplement. Since not all the spontaneous fission energy distributions for the different isotopes of an element are known at present but are considered to be quite similar,[5] values given in the table for an element have been used for all isotopes of that element. Also, in cases where values are not available from the literature[5] for an element (e.g. Pu) inference from neighboring elements was made.

In keeping with the assumptions made in ICRP Publication 2, n, the relative damage factor for radionuclides deposited in bone, was taken as 1 and 5 respectively, for the gamma- and beta-radiations arising from spontaneous fission. Since the kinetic energy of the fragments and the neutron components were considered to be as damaging as alpha-rays, n was taken equal to 5 for these energies. A QF* value of 20 was used for the kinetic energy of fission fragments. This value was recommended by ICRP Committee II at its meeting in New York, September, 1961. Using Fig. 14 of the United States National Bureau of Standards Handbook 63[6] as a guide, the QF of spontaneous fission neutrons was taken equal to 8; and, as in ICRP Publication 2, a QF of 1 was used for the beta and gamma components. In computing effective energies for the GI tract, only 1 per cent of the kinetic energy release of the fragments was included as was done in ICRP Publication 2 since it was assumed that this energy, like the energy from alpha-particles, would fail to penetrate the mucosa to an appreciable extent.

REFERENCES

1. E. K. Hyde, The Radioactive Decay of the Isotopes of the Transuranium Elements UCRL–9148 (January 1961); UCRL–9036 (January 1960).

* See the discussion of RBE and QF in Part 3 of this publication.

2. LANDOLT-BORNSTEIN, New Series, Energy Levels of Nuclei: $A = 5$ to $A = 257$ (September 1961).
3. A. B. SMITH, P. R. FIELDS and A. M. FRIEDMAN, Prompt gamma-rays accompanying the spontaneous fission of Cf^{252}, *Phys. Rev.* **104** (3), 699 (1 Nov. 1956).
4. SAMUEL GLASSTONE, *Principles of Nuclear Reactor Engineering*, Van Nostrand, 1955, p. 22.
5. H. W. SCHMITT and G. D. O'KELLEY, ORNL, Private communication.
6. *Protection Against Neutron Radiation up to* 30 *million Electron Volts*. Report of National Committee on Radiation Protection, National Bureau of Standards Handbook 63. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. (1957).

TABLE A. DISTRIBUTION OF SPONTANEOUS FISSION ENERGY

Radionuclide	U^{235} (Neutron induced)	Pu	Cm	Cf	En	Fm
Kinetic energy of fragments (MeV)*	167.0		(180.0)	185.0	(180.0)	176.0
ν (neutrons/fission)*	2.42		(2.8)	3.86	(3.95)	4.05
Energy/neutron* (average-MeV)	2.0		(2.0)	2.15	(2.18)	2.2
Total gamma-ray per fission* Prompt (av-MeV) Delayed (av-MeV)	7.5 (first few μsec) (+10−20% for γ's up to a msec)		(9.0) (+10−20%)	9.0 (+10−20%)	(9.0) (+10−20%)	(8.5) (+10−20%)
Energy prompt gamma/fission* (average-MeV)	0.8		(0.8)	0.8–0.9	(~0.9)	(~0.9)
Total average beta-energy from fission products/fission† (MeV)	7.6	(7.5)	(7.4)	(7.0)	(7.0)	(7.0)
Energy/β† (average-MeV)	1.2	(1.17)	(1.12)	(1.05)	(1.05)	(1.05)
Total gamma-energy from fission products/fission† (MeV)	6.0	(5.8)	(5.6)	(5.2)	(5.2)	(5.2)
Energy/fission product γ† (average-MeV)	1.6 at 10^2 sec 0.5 at 10^5 sec Average ~1.3	(1.26)	(1.19)	(1.15)	(1.15)	(1.15)

Values in parentheses were estimated from measured values of neighboring elements.

* From literature survey by H. W. Schmitt, Oak Ridge, Tennessee. Private communication.

† From literature survey by G. D. O'Kelley, Oak Ridge, Tennessee. Private communication.

1962 SUPPLEMENT TO ICRP PUBLICATION 2, TABLE 1

Maximum permissible body-burdens and maximum permissible concentrations of radionuclides in air and water for occupational exposure

Radionuclide and type of decay		Organ of reference* (critical organ **bold face**)	Maximum permissible burden in total body $q(\mu c)$	Maximum permissible concentrations			
				For 40-hr week		For 168-hr week	
				$(MPC)_w$ $(\mu c/cm^3)$	$(MPC)_a$ $(\mu c/cm^3)$	$(MPC)_w$ $(\mu c/cm^3)$	$(MPC)_a$ $(\mu c/cm^3)$
$_{38}Sr^{90}$† β^-	(sol.)	**Bone**	2.0	$\mathbf{10^{-5}}$	$\mathbf{10^{-9}}$	$\mathbf{4 \times 10^{-6}}$	$\mathbf{4 \times 10^{-10}}$
		Total body	3.0	2×10^{-5}	2×10^{-9}	7×10^{-6}	7×10^{-10}
		GI(LLI)		10^{-3}	3×10^{-7}	5×10^{-4}	10^{-7}
	(insol.)	**Lung**			$\mathbf{5 \times 10^{-9}}$		$\mathbf{2 \times 10^{-9}}$
		GI(LLI)		$\mathbf{10^{-3}}$	2×10^{-7}	$\mathbf{4 \times 10^{-4}}$	6×10^{-8}
$_{92}U^{230}$† α, β^-, γ	(sol.)	**Kidney**	0.01	$\mathbf{7 \times 10^{-5}}$	$\mathbf{3 \times 10^{-10}}$	$\mathbf{2 \times 10^{-5}}$	$\mathbf{10^{-10}}$
		GI(LLI)		10^{-4}	3×10^{-8}	5×10^{-5}	10^{-8}
		Total body	0.06	3×10^{-4}	10^{-9}	10^{-4}	5×10^{-10}
		Bone	7×10^{-3}	4×10^{-4}	2×10^{-9}	2×10^{-4}	6×10^{-10}
	(insol.)	**Lung**			$\mathbf{10^{-10}}$		$\mathbf{4 \times 10^{-11}}$
		GI(LLI)		$\mathbf{10^{-4}}$	2×10^{-8}	$\mathbf{5 \times 10^{-5}}$	8×10^{-9}
$_{92}U^{232}$† $\alpha, \beta^-, \gamma, e^-$	(sol.)	**Bone**	0.01	$\mathbf{2 \times 10^{-5}}$	$\mathbf{10^{-10}}$	$\mathbf{8 \times 10^{-6}}$	$\mathbf{3 \times 10^{-11}}$
		Total body	0.07	6×10^{-5}	3×10^{-10}	2×10^{-5}	10^{-10}
		Kidney	0.04	10^{-4}	6×10^{-10}	4×10^{-5}	2×10^{-10}
		GI(LLI)		8×10^{-4}	2×10^{-7}	3×10^{-4}	6×10^{-8}
	(insol.)	**Lung**			$\mathbf{3 \times 10^{-11}}$		$\mathbf{9 \times 10^{-12}}$
		GI(LLI)		$\mathbf{8 \times 10^{-4}}$	10^{-7}	$\mathbf{3 \times 10^{-4}}$	5×10^{-8}
$_{92}U^{233}$† α, γ	(sol.)	**Bone**	0.05	$\mathbf{10^{-4}}$	$\mathbf{5 \times 10^{-10}}$	$\mathbf{4 \times 10^{-5}}$	$\mathbf{2 \times 10^{-10}}$
		Kidney	0.08	3×10^{-4}	10^{-9}	10^{-4}	4×10^{-10}
		Total body	0.4	4×10^{-4}	2×10^{-9}	10^{-4}	5×10^{-10}
		GI(LLI)		9×10^{-4}	2×10^{-7}	3×10^{-4}	7×10^{-8}
	(insol.)	**Lung**			$\mathbf{10^{-10}}$		$\mathbf{4 \times 10^{-11}}$
		GI(LLI)		$\mathbf{9 \times 10^{-4}}$	2×10^{-7}	$\mathbf{3 \times 10^{-4}}$	6×10^{-8}
$_{92}U^{234}$† α, γ	(sol.)	**Bone**	0.05	$\mathbf{10^{-4}}$	$\mathbf{6 \times 10^{-10}}$	$\mathbf{4 \times 10^{-5}}$	$\mathbf{2 \times 10^{-10}}$
		Kidney	0.08	3×10^{-4}	10^{-9}	10^{-4}	4×10^{-10}
		Total body	0.4	4×10^{-4}	2×10^{-9}	10^{-4}	6×10^{-10}
		GI(LLI)		9×10^{-4}	2×10^{-7}	3×10^{-4}	7×10^{-8}
	(insol.)	**Lung**			$\mathbf{10^{-10}}$		$\mathbf{4 \times 10^{-11}}$
		GI(LLI)		$\mathbf{9 \times 10^{-4}}$	2×10^{-7}	$\mathbf{3 \times 10^{-4}}$	6×10^{-8}

* The abbreviations GI, S, SI, ULI, and LLI refer to gastrointestinal tract, stomach, small intestine, upper large intestine, and lower large intestine, respectively.

† This listing revises some values given in ICRP Publication 2. For completeness, all values for the indicated organ of reference are given even though some values are unchanged. When applying the short-term exposure rule (paragraph 52e) to uranium, the chemical toxicity limits specified under paragraph 52f must not be exceeded.

Table 1—continued

Radionuclide and type of decay		Organ of reference (critical organ **bold face**)	Maximum permissible burden in total body $q(\mu c)$	Maximum permissible concentrations			
				For 40-hr week		For 168-hr week	
				$(MPC)_w$ ($\mu c/cm^3$)	$(MPC)_a$ ($\mu c/cm^3$)	$(MPC)_w$ ($\mu c/cm^3$)	$(MPC)_a$ ($\mu c/cm^3$)
$_{92}U^{235}$† α, β^-, γ	(sol.)	**Kidney**	0.03	10^{-4}	5×10^{-10}	4×10^{-5}	2×10^{-10}
		Bone	0.06	10^{-4}	6×10^{-10}	5×10^{-5}	2×10^{-10}
		Total body	0.4	4×10^{-4}	2×10^{-9}	10^{-4}	6×10^{-10}
		GI(LLI)		8×10^{-4}	2×10^{-7}	3×10^{-4}	6×10^{-8}
	(insol.)	**Lung**			10^{-10}		4×10^{-11}
		GI(LLI)		8×10^{-4}	10^{-7}	3×10^{-4}	5×10^{-8}
$_{92}U^{236}$† α, γ	(sol.)	**Bone**	0.06	10^{-4}	6×10^{-10}	5×10^{-5}	2×10^{-10}
		Kidney	0.08	3×10^{-4}	10^{-9}	10^{-4}	4×10^{-10}
		Total body	0.4	4×10^{-4}	2×10^{-9}	10^{-4}	6×10^{-10}
		GI(LLI)		10^{-3}	2×10^{-7}	3×10^{-4}	7×10^{-8}
	(insol.)	**Lung**			10^{-10}		4×10^{-11}
		GI(LLI)		10^{-3}	2×10^{-7}	3×10^{-4}	6×10^{-8}
$_{92}U^{238}$† α, γ, e^-	(sol.)	**Kidney**	5×10^{-3}	2×10^{-5}	7×10^{-11}	6×10^{-6}	3×10^{-11}
		Bone	0.06	10^{-4}	6×10^{-10}	5×10^{-5}	2×10^{-10}
		Total body	0.5	4×10^{-4}	2×10^{-9}	10^{-4}	6×10^{-10}
		GI(LLI)		10^{-3}	2×10^{-7}	4×10^{-4}	8×10^{-8}
	(insol.)	**Lung**			10^{-10}		5×10^{-11}
		GI(LLI)		10^{-3}	2×10^{-7}	4×10^{-4}	6×10^{-8}
$_{92}$U-nat† $\alpha, \beta^-, \gamma, e^-$	(sol.)	**Kidney**	5×10^{-3}	2×10^{-5}	7×10^{-11}	6×10^{-6}	3×10^{-11}
		Bone	0.03	6×10^{-5}	3×10^{-10}	2×10^{-5}	10^{-10}
		Total body	0.2	2×10^{-4}	8×10^{-10}	7×10^{-5}	3×10^{-10}
		GI(LLI)		5×10^{-4}	10^{-7}	2×10^{-4}	4×10^{-8}
	(insol.)	**Lung**			6×10^{-11}		2×10^{-11}
		GI(LLI)		5×10^{-4}	8×10^{-8}	2×10^{-4}	3×10^{-8}
$_{92}U^{240}+Np^{240}$ $\alpha, \beta^-, \gamma, e^-$	(sol.)	**GI(LLI)**		10^{-3}	2×10^{-7}	3×10^{-4}	8×10^{-8}
		Kidney	4.0	0.4	2×10^{-6}	0.1	5×10^{-7}
		Total body	20.0	2.0	10^{-5}	0.8	4×10^{-6}
		Bone	2.0	3.0	10^{-5}	1.0	4×10^{-6}
	(insol.)	**GI(LLI)**		10^{-3}	2×10^{-7}	3×10^{-4}	6×10^{-8}
		Lung			10^{-6}		5×10^{-7}

† This listing revises some values given in ICRP Publication 2. For completeness, all values for the indicated organ of reference are given even though some values are unchanged. When applying the short-term exposure rule (paragraph 52e) to uranium, the chemical toxicity limits specified under paragraph 52f must not be exceeded.

Table 1—continued

Radionuclide and type of decay		Organ of reference (critical organ **bold face**)	Maximum permissible burden in total body $q(\mu c)$	Maximum permissible concentrations			
				For 40-hr week		For 168-hr week	
				$(MPC)_w$ ($\mu c/cm^3$)	$(MPC)_a$ ($\mu c/cm^3$)	$(MPC)_w$ ($\mu c/cm^3$)	$(MPC)_a$ ($\mu c/cm^3$)
$_{94}Pu^{243}$ $\alpha, \beta^-, \gamma, e^-$	(sol.)	**GI(ULI)**		**0.01**	**2×10^{-6}**	**3×10^{-8}**	**6×10^{-7}**
		Bone	7.0	10^3	10^{-5}	400	5×10^{-6}
		Kidney	30.0	5×10^3	7×10^{-5}	2×10^3	2×10^{-5}
		Liver	40.0	6×10^3	7×10^{-5}	2×10^3	3×10^{-5}
		Total body	50.0	8×10^3	10^{-4}	3×10^3	4×10^{-5}
	(insol.)	**GI(ULI)**		**0.01**	**2×10^{-6}**	**3×10^{-8}**	**8×10^{-7}**
		Lung			2×10^{-5}		6×10^{-6}
$_{94}Pu^{244}$ $\alpha, \beta^-, \gamma, e^-$ (99.7%) Spontaneous fission (0.3%)	(sol.)	**Bone**	0.04	10^{-4}	**2×10^{-12}**	**4×10^{-5}**	**6×10^{-12}**
		GI(LLI)		3×10^{-4}	7×10^{-8}	10^{-4}	2×10^{-8}
		Kidney	0.4	6×10^{-4}	8×10^{-12}	2×10^{-4}	3×10^{-12}
		Total body	0.3	9×10^{-4}	10^{-11}	3×10^{-4}	4×10^{-12}
	(insol.)	**Lung**			**3×10^{-11}**		**10^{-11}**
		GI(LLI)		**3×10^{-4}**	6×10^{-8}	**10^{-4}**	2×10^{-8}
$_{95}Am^{242m}$ $\alpha, \beta^-, \gamma, \epsilon, e^-$	(sol.)	**Bone**	0.07	10^{-4}	**6×10^{-12}**	**4×10^{-5}**	**2×10^{-12}**
		Kidney	0.1	10^{-4}	**6×10^{-12}**	5×10^{-5}	**2×10^{-12}**
		Liver	0.3	2×10^{-4}	9×10^{-11}	7×10^{-5}	3×10^{-12}
		Total body	0.3	3×10^{-4}	2×10^{-11}	10^{-4}	5×10^{-12}
		GI(LLI)		3×10^{-3}	6×10^{-7}	9×10^{-4}	2×10^{-7}
	(insol.)	**Lung**			**3×10^{-10}**		**9×10^{-11}**
		GI(LLI)		**3×10^{-3}**	5×10^{-7}	**9×10^{-4}**	2×10^{-7}
$_{95}Am^{242}$ $\alpha, \beta^-, \gamma, \epsilon, e^-$	(sol.)	**GI(LLI)**		**4×10^{-3}**	**8×10^{-7}**	**10^{-3}**	3×10^{-7}
		Liver	0.06	0.9	**4×10^{-8}**	0.3	**10^{-8}**
		Kidney	0.1	2.0	8×10^{-8}	0.6	3×10^{-8}
		Bone	0.1	2.0	8×10^{-8}	0.6	3×10^{-8}
		Total body	0.3	4.0	2×10^{-7}	1.0	6×10^{-8}
	(insol.)	**Lung**			**5×10^{-8}**		**2×10^{-8}**
		GI(LLI)		**4×10^{-3}**	7×10^{-7}	**10^{-3}**	2×10^{-7}
$_{95}Am^{244}$ $\alpha, \beta^-, \gamma, e^-$	(sol.)	**GI(SI)**		**0.1**	3×10^{-5}	**0.05**	10^{-5}
		Bone	0.2	90.0	**4×10^{-6}**	30.0	**10^{-6}**
		Kidney	0.2	100.0	**4×10^{-6}**	30.0	**10^{-6}**
		Liver	0.2	100.0	5×10^{-6}	40.0	2×10^{-6}
		Total body	0.4	200.0	10^{-5}	80.0	3×10^{-6}
	(insol.)	**Lung**			**2×10^{-5}**		**8×10^{-6}**
		GI(SI)		**0.1**	**2×10^{-5}**	**0.05**	**8×10^{-6}**

Table 1—continued

Radionuclide and type of decay		Organ of reference (critical organ **bold face**)	Maximum permissible burden in total body $q(\mu c)$	Maximum permissible concentrations			
				For 40-hr week		For 168-hr week	
				$(MPC)_w$ ($\mu c/cm^3$)	$(MPC)_a$ ($\mu c/cm^3$)	$(MPC)_w$ ($\mu c/cm^3$)	$(MPC)_a$ ($\mu c/cm^3$)
$_{96}Cm^{247}$ $\alpha, \beta^-, \gamma, e^-$	(sol.)	**Bone**	0.04	$\mathbf{10^{-4}}$	$\mathbf{5 \times 10^{-12}}$	$\mathbf{4 \times 10^{-5}}$	$\mathbf{2 \times 10^{-12}}$
		Liver	0.5	2×10^{-4}	9×10^{-12}	7×10^{-5}	3×10^{-12}
		Kidney	0.2	2×10^{-4}	9×10^{-12}	7×10^{-5}	3×10^{-12}
		Total body	0.4	3×10^{-4}	10^{-11}	10^{-4}	5×10^{-12}
		GI(LLI)		6×10^{-4}	10^{-7}	2×10^{-4}	5×10^{-8}
	(insol.)	**Lung**			$\mathbf{10^{-10}}$		$\mathbf{4 \times 10^{-11}}$
		GI(LLI)		$\mathbf{6 \times 10^{-4}}$	10^{-7}	$\mathbf{2 \times 10^{-4}}$	4×10^{-8}
$_{96}Cm^{248}$ α (89%) Spontaneous fission (11%)	(sol.)	**Bone**	$\mathbf{5 \times 10^{-3}}$	$\mathbf{10^{-5}}$	$\mathbf{6 \times 10^{-12}}$	$\mathbf{4 \times 10^{-6}}$	$\mathbf{2 \times 10^{-12}}$
		Liver	0.06	2×10^{-5}	10^{-12}	8×10^{-6}	4×10^{-12}
		Kidney	0.03	3×10^{-5}	10^{-12}	9×10^{-6}	4×10^{-12}
		Total body	0.04	4×10^{-5}	2×10^{-12}	10^{-5}	6×10^{-12}
		GI(LLI)		4×10^{-5}	8×10^{-9}	10^{-5}	3×10^{-9}
	(insol.)	**Lung**			$\mathbf{10^{-11}}$		$\mathbf{4 \times 10^{-12}}$
		GI(LLI)		$\mathbf{4 \times 10^{-5}}$	7×10^{-9}	$\mathbf{10^{-5}}$	2×10^{-9}
$_{96}Cm^{249}$ $\alpha, \beta^-, \gamma, e^-$	(sol.)	**GI(S)**		**0.06**	$\mathbf{10^{-5}}$	**0.02**	$\mathbf{5 \times 10^{-6}}$
		Bone	1.0	300.0	$\mathbf{10^{-5}}$	100.0	$\mathbf{4 \times 10^{-6}}$
		Total body	4.0	800.0	3×10^{-5}	300.0	10^{-5}
	(insol.)	**GI(S)**		**0.06**	$\mathbf{10^{-5}}$	**0.02**	$\mathbf{4 \times 10^{-6}}$
		Lung			5×10^{-5}		2×10^{-5}
$_{97}Bk^{250}$ $\alpha, \beta^-, \gamma, e^-$	(sol.)	**GI(ULI)**		$\mathbf{6 \times 10^{-3}}$	$\mathbf{10^{-6}}$	$\mathbf{2 \times 10^{-3}}$	5×10^{-7}
		Bone	0.05	10.0	$\mathbf{10^{-7}}$	4.0	$\mathbf{5 \times 10^{-8}}$
		Total body	0.3	80.0	10^{-6}	30.0	4×10^{-7}
	(insol.)	**GI(ULI)**		$\mathbf{6 \times 10^{-3}}$	$\mathbf{10^{-6}}$	$\mathbf{2 \times 10^{-3}}$	$\mathbf{4 \times 10^{-7}}$
		Lung			2×10^{-6}		8×10^{-7}
$_{98}Cf^{251}$ α, γ	(sol.)	**Bone**	0.04	$\mathbf{10^{-4}}$	$\mathbf{2 \times 10^{-12}}$	$\mathbf{4 \times 10^{-5}}$	$\mathbf{6 \times 10^{-13}}$
		GI(LLI)		8×10^{-4}	2×10^{-7}	3×10^{-4}	6×10^{-8}
		Total body	0.3	9×10^{-4}	10^{-11}	3×10^{-4}	4×10^{-12}
	(insol.)	**Lung**			$\mathbf{10^{-10}}$		$\mathbf{3 \times 10^{-11}}$
		GI(LLI)		$\mathbf{8 \times 10^{-4}}$	10^{-7}	$\mathbf{3 \times 10^{-4}}$	5×10^{-8}
$_{98}Cf^{253}$ $\alpha, \beta^-, \gamma, e^-$	(sol.)	**GI(LLI)**		$\mathbf{4 \times 10^{-3}}$	9×10^{-7}	$\mathbf{10^{-3}}$	3×10^{-7}
		Bone	0.04	0.06	$\mathbf{8 \times 10^{-10}}$	0.02	$\mathbf{3 \times 10^{-10}}$
		Total body	0.3	0.5	6×10^{-9}	0.2	2×10^{-9}
	(insol.)	**Lung**			$\mathbf{8 \times 10^{-10}}$		$\mathbf{3 \times 10^{-10}}$
		GI(LLI)		$\mathbf{4 \times 10^{-3}}$	7×10^{-7}	$\mathbf{10^{-3}}$	3×10^{-7}

Table 1—continued

Radionuclide and type of decay		Organ of reference (critical organ **bold face**)	Maximum permissible burden in total body $q(\mu c)$	Maximum permissible concentrations			
				For 40-hr week		For 168-hr week	
				$(MPC)_w$ ($\mu c/cm^3$)	$(MPC)_a$ ($\mu c/cm^3$)	$(MPC)_w$ ($\mu c/cm^3$)	$(MPC)_a$ ($\mu c/cm^3$)
$_{98}Cf^{254}$ Spontaneous fission	(sol.)	**GI(LLI)**		**4×10^{-6}**	**8×10^{-10}**	**10^{-6}**	**3×10^{-10}**
		Bone	7×10^{-4}	4×10^{-4}	**5×10^{-12}**	10^{-4}	**2×10^{-12}**
		Total body	5×10^{-3}	3×10^{-3}	4×10^{-11}	10^{-3}	10^{-11}
	(insol.)	**Lung**			**5×10^{-12}**		**2×10^{-12}**
		GI(LLI)		**4×10^{-6}**	**6×10^{-10}**	**10^{-6}**	2×10^{-10}
$_{99}Es^{253}$ $\alpha, \beta^-, \gamma, e^-$	(sol.)	**GI(LLI)**		**7×10^{-4}**	10^{-7}	**2×10^{-4}**	5×10^{-8}
		Bone	0.04	0.06	**8×10^{-10}**	0.02	**3×10^{-10}**
		Total body	0.3	0.4	5×10^{-9}	0.1	2×10^{-9}
	(insol.)	**Lung**			**6×10^{-10}**		**2×10^{-10}**
		GI(LLI)		**7×10^{-4}**	10^{-7}	**2×10^{-4}**	4×10^{-8}
$_{99}Es^{254m}$ $\alpha, \beta^-, \gamma, e^-$	(sol.)	**GI(LLI)**		**5×10^{-4}**	10^{-7}	**2×10^{-4}**	4×10^{-8}
		Bone	0.02	0.4	**5×10^{-9}**	0.1	**2×10^{-9}**
		Total body	0.1	3.0	4×10^{-8}	1.0	10^{-8}
	(insol.)	**Lung**			**6×10^{-9}**		**2×10^{-9}**
		GI(LLI)		**5×10^{-4}**	10^{-7}	**2×10^{-4}**	3×10^{-8}
$_{99}Es^{254}$ $\alpha, \beta^-, \gamma, e^-$	(sol.)	**GI(LLI)**		**4×10^{-4}**	9×10^{-8}	**10^{-4}**	3×10^{-8}
		Bone	0.02	10^{-3}	**2×10^{-11}**	5×10^{-4}	**6×10^{-12}**
		Total body	0.2	10^{-2}	10^{-10}	3×10^{-3}	5×10^{-11}
	(insol.)	**Lung**			**10^{-10}**		**4×10^{-11}**
		GI(LLI)		**4×10^{-4}**	7×10^{-8}	**10^{-4}**	3×10^{-8}
$_{99}Es^{255}$ α, β^-, γ	(sol.)	**GI(LLI)**		**8×10^{-4}**	2×10^{-7}	**3×10^{-4}**	6×10^{-8}
		Bone	0.04	0.04	**5×10^{-10}**	0.01	**2×10^{-10}**
		Total body	0.3	0.3	4×10^{-9}	0.09	10^{-9}
	(insol.)	**Lung**			**4×10^{-10}**		**10^{-10}**
		GI(LLI)		**8×10^{-4}**	10^{-7}	**3×10^{-4}**	5×10^{-8}
$_{100}Fm^{254}$ α, γ, e^- (99.9448%) Spontaneous fission (5.52 × 10⁻²%)	(sol.)	**GI(ULI)**		**4×10^{-3}**	8×10^{-7}	**10^{-3}**	3×10^{-7}
		Bone	0.02	5.0	**6×10^{-8}**	2.0	**2×10^{-8}**
		Total body	0.1	30.0	4×10^{-7}	10.0	2×10^{-7}
	(insol.)	**Lung**			**7×10^{-8}**		**2×10^{-8}**
		GI(ULI)		**4×10^{-3}**	6×10^{-7}	**10^{-3}**	2×10^{-7}
$_{100}Fm^{255}$ α, γ	(sol.)	**GI(LLI)**		**10^{-3}**	2×10^{-7}	**3×10^{-4}**	7×10^{-8}
		Bone	0.04	1.0	**2×10^{-8}**	0.4	**6×10^{-9}**
		Total body	0.3	9.0	10^{-7}	3.0	4×10^{-8}

Table 1—continued

Radionuclide and type of decay	Organ of reference (critical organ **bold face**)	Maximum permissible burden in total body $q(\mu c)$	Maximum permissible concentrations			
			For 40-hr week		For 168-hr week	
			$(MPC)_w$ ($\mu c/cm^3$)	$(MPC)_a$ ($\mu c/cm^3$)	$(MPC)_w$ ($\mu c/cm^3$)	$(MPC)_a$ ($\mu c/cm^3$)
	(insol.)	**Lung**		**10^{-8}**		**4×10^{-9}**
		GI(LLI)	**10^{-3}**	2×10^{-7}	**3×10^{-4}**	6×10^{-8}
$_{100}Fm^{256}$ Spontaneous fission	(sol.)	**GI(ULI)**	**3×10^{-5}**	6×10^{-9}	**9×10^{-6}**	2×10^{-9}
		Bone	8×10^{-4}	0.2	3×10^{-9}	0.07	**10^{-9}**
		Total body	5×10^{-3}	1.0	2×10^{-8}	0.5	7×10^{-9}
	(insol.)	**Lung**		**2×10^{-9}**		**6×10^{-10}**
		GI(ULI)	**3×10^{-5}**	5×10^{-9}	**9×10^{-6}**	2×10^{-9}

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Effective Energies

Z	Radionuclide (T_r in days)	Organ of reference*	$\Sigma EF(\mathrm{RBE})n$ (E in MeV)
92	U^{240} + Np^{240} (0.59)	Total body	1.3
		Lung	0.90
		Kidney	1.1
		Bone	5.3
94	Pu^{243} (0.21) + drs	Total body	0.37
		Lung (insol.)	0.19
		Bone	2.0
		Kidney	0.37
		Liver	0.25
94	Pu^{244} (2.8×10^{10}) + drs } 99.7%	Total body	48.0
		Lung (insol.)	48.0
		Bone	240.0
		Kidney	48.0
94	Pu^{244} (9.1×10^{13}) + drs } S.F. 0.3%	Total body	3500.0
		Lung (insol.)	3500.0
		GI	99.0
		Bone	17600.0
		Kidney	3500.0
95	Am^{242m} (5.6×10^{4}) + drs } 16%	Total body	0.17
		Lung (insol.)	0.11
		Bone	0.25
		Kidney	0.097
		Liver	0.11
95	Am^{242m} (5.6×10^{4}) + drs } 84%	Total body	73.0
		Lung (insol.)	27.0
		Bone	360.0
		Kidney	72.0
		Liver	68.0
95	Am^{242} (0.67) Pu^{242} (1.4×10^{8}) } 16%	Total body	0.13
		Lung (insol.)	0.088
		Bone	0.25
		Kidney	0.084
		Liver	0.092
95	Am^{242} (0.67) + drs } 84%	Total body	80.0
		Lung (insol.)	27.0
		Bone	400.0
		Kidney	78.0
		Liver	75.0
95	Am^{244} (0.018) + drs	Total body	44.0
		Lung (insol.)	1.6
		Bone	250.0
		Kidney	44.0
		Liver	20.0
96	Cm^{247} (3.3×10^{10}) + drs	Total body	55.0
		Lung (insol.)	55.0
		Bone	270.0
		Kidney	55.0
		Liver	55.0
96	Cm^{248} (1.7×10^{8}) } 89%	Total body	52.0
		Lung (insol.)	52.0
		GI(S)	0.51
		GI(SI)	0.51
		GI(LI)	0.51
		Bone	260.0
		Kidney	52.0
		Liver	52.0

Table 5—continued

Z	Radionuclide (T_r in days)	Organ of reference*	$\Sigma EF(\text{RBE})n$ (E in MeV)	Z	Radionuclide (T_r in days)	Organ of reference*	$\Sigma EF(\text{RBE})n$ (E in MeV)
96	Cm^{248} (S.F. 11%) (1.7×10^9)	Total body	3700.0				
		Lung (insol.)	3700.0	99	Es^{254m}	Total body	130.0
		GI	100.0		(1.60)	Lung (insol.)	76.0
		Bone	18300.0		+ drs	Bone	660.0
		Kidney	3700.0				
		Liver	3700.0	99	Es^{254}	Total body	120.0
					(480)	Lung (insol.)	69.0
96	Cm^{249}	Total body	5.2		+ drs	Bone	620.0
	(0.044)	Lung (insol.)	0.31				
	+ drs	Bone	27.0	99	Es^{255}	Total body	75.0
					(30)	Lung (insol.)	73.0
97	Bk^{250}	Total body	57.0		+ drs	Bone	380.0
	(0.13)	Lung (insol.)	2.3				
		Bone	290.0	100	Fm^{254} (99.9448%)	Total body	130.0
					(0.14)	Lung (insol.)	76.0
98	Cf^{251}	Total body	59.0		+ drs	Bone	660.0
	(2.9×10^5)	Lung (insol.)	59.0				
		GI(S)	0.61	100	Fm^{254} (S.F. 5.52×10^{-2}%)	Total body	3600.0
		GI(SI)	0.65		(246)	Lung (insol.)	3600.0
		GI(LI)	0.59			GI	130.0
		Bone	290.0			Bone	18000.0
98	Cf^{253}	Total body	73.0	100	Fm^{255}	Total body	75.0
	(18)	Lung (insol.)	59.0		(0.896)	Lung (insol.)	73.0
	+ drs	Bone	370.0		+ drs	Bone	380.0
98	Cf^{254}	Total body	3800.0	100	Fm^{256}	Total body	3600.0
	(56)	Lung (insol.)	3800.0		(0.111)	Lung (insol.)	3600.0
		GI	120.0			GI	130.0
		Bone	18900.0			Bone	18000.0
99	Es^{253}	Total body	73.0				
	(20)	Lung (insol)	68.0				
	+ drs	Bone	370.0				

* The abbreviations GI, S, SI, and LI refer to gastrointestinal tract, stomach, small intestine, and large intestine (either upper or lower large intestine), respectively.

1962 SUPPLEMENT TO ICRP PUBLICATION 2, TABLE 5a
Effective Energies for Chains

Radionuclide	Half-life (T_r in days)	Effective energy for organs of reference				ΣE(RBE) (E in MeV) for GI tract*		
		Organs of Reference	ΣE(RBE)n (E in MeV)	F	ΣEF(RBE)n (E in MeV)	S	SI	LI
$_{94}U^{240}$	0.59	Total body	1.0	1.0	1.0	0.89	1.0	0.84
Np^{240}		Lung (insol.)	0.89	1.0	0.89			
		Kidney	0.87	1.0	0.87			
		Bone	4.0	1.0	4.0			
Pu^{240}	2.4×10^6	Total body	53.0	0.0048	0.25	0.52	0.52	0.52
		Lung (insol.)	53.0	1.5×10^{-4}	0.0081			
		Kidney	53.0	0.0044	0.23			
		Bone	266.0	0.0048	1.3			
		Total body	Totals for Chain		1.3			
		Lung (insol.)			0.90			
		Kidney			1.1			
		Bone			5.3			
$_{94}Pu^{243}$	0.21	Total body	0.19	1.0	0.19	0.18	0.19	0.18
		Lung (insol.)	0.18	1.0	0.18			
		Bone	0.88	1.0	0.88			
		Kidney	0.18	1.0	0.18			
		Liver	0.18	1.0	0.18			
Am^{243}	2.9×10^6	Total body	54.0	0.0032	0.17	0.55	0.57	0.55
		Lung (insol.)	54.0	4.1×10^{-5}	0.0022			
		Bone	272.0	0.0040	1.08			
		Kidney	54.0	0.0035	0.19			
		Liver	54.0	0.0012	0.064			
Np^{239}	2.33	Total body	0.33	0.0032	0.0011	0.27	0.33	0.24
		Lung (insol.)	0.27	4.0×10^{-5}	1.0×10^{-4}			
		Bone	1.1	0.0040	0.0043			
		Kidney	0.25	0.0035	9.0×10^{-4}			
		Liver	0.27	0.0012	3.0×10^{-4}			
		Total body	Totals for Chain		0.37			
		Lung (insol.)			0.19			
		Bone			2.0			
		Kidney			0.37			
		Liver			0.25			

* The abbreviations GI, S, SI, and LI refer to gastrointestinal tract, stomach, small intestine, and large intestine either upper or lower large intestine), respectively.

Table 5a—*continued*

Radionuclide	Half-life (T_r in days)	Effective energy for organs of reference				ΣE(RBE) (E in MeV) for GI tract		
		Organs of Reference	ΣE(RBE)n (E in MeV)	F	ΣEF(RBE)n (E in MeV)	S	SI	LI
$_{94}Pu^{244}$	2.8×10^{10}	Total body	47.0	1.0	47.0	0.46	0.46	0.46
		Lung (insol.)	47.0	1.0	47.0			
		Bone	235.0	1.0	235.0			
		Kidney	47.0	1.0	47.0			
U^{240} 99.7 %	0.59	Total body	1.0	1.0	1.0	0.89	1.0	0.84
Np^{240}		Lung (insol.)	0.89	1.0	0.89			
		Bone	4.0	1.0	4.0			
		Kidney	0.86	0.97	0.83			
Pu^{240}	2.4×10^{6}	Total body	53.0	0.0026	0.14	0.52	0.52	0.52
		Lung (insol.)	53.0	1.5×10^{-4}	0.080			
		Bone	266.0	0.0026	0.68			
		Kidney	53.0	0.0024	0.13			
		Total body	Totals for Chain		48.0			
		Lung (insol.)			48.0			
		Bone			240.0			
		Kidney			48.0			
$_{95}Am^{242m}$	5.6×10^{4}	Total body	0.037	1.0	0.037	0.019	0.037	0.011
		Lung (insol.)	0.019	1.0	0.019			
		Bone	0.011	1.0	0.011			
		Kidney	0.014	1.0	0.014			
		Liver	0.019	1.0	0.019			
Am^{242} 16 %	0.67	Total body	0.13	1.0	0.13	0.089	0.13	0.073
		Lung (insol.)	0.089	0.99	0.088			
		Bone	0.23	1.0	0.23			
		Kidney	0.080	1.0	0.080			
		Liver	0.089	1.0	0.089			
Pu^{242}	1.4×10^{8}	Total body	51.0	4.9×10^{-5}	0.0025	0.49	0.50	0.49
		Lung (insol.)	51.0	2.6×10^{-6}	10^{-4}			
		Bone	253.0	4.6×10^{-5}	0.012			
		Kidney	51.0	4.5×10^{-5}	0.0023			
		Liver	51.0	5.9×10^{-5}	0.0030			
		Total body	Totals for Chain		0.17			
		Lung (insol.)			0.11			
		Bone			0.25			
		Kidney			0.097			
		Liver			0.11			

Table 5a—*continued*

Radionuclide	Half-life (T_r in days)	Effective energy for organs of reference				ΣE(RBE) (E in MeV) for GI tract		
		Organs of Reference	ΣE(RBE)n (E in MeV)	F	ΣEF(RBE)n (E in MeV)	S	SI	LI
$_{95}Am^{242m}$	5.6×10^4	Total body	0.037	1.0	0.037	0.019	0.037	0.011
		Lung (insol.)	0.019	1.0	0.019			
		Bone	0.011	1.0	0.011			
		Kidney	0.014	1.0	0.014			
		Liver	0.019	1.0	0.019			
Am^{242}	0.67	Total body	0.24	1.0	0.24	0.24	0.24	0.23
84 %		Lung (insol.)	0.24	0.99	0.23			
		Bone	1.1	1.0	1.1			
		Kidney	0.24	1.0	0.24			
		Liver	0.24	1.0	0.24			
Cm^{242}	162.5	Total body	63.0	0.99	62.0	0.63	0.63	0.63
		Lung (insol.)	63.0	0.42	27.0			
		Bone	315.0	0.98	310.0			
		Kidney	63.0	0.98	62.0			
		Liver	63.0	0.94	59.0			
Pu^{238}	3.2×10^4	Total body	57.0	0.18	10.0	0.57	0.57	0.57
		Lung (insol.)	57.0	0.0048	0.27			
		Bone	283.0	0.17	49.0			
		Kidney	57.0	0.17	9.5			
		Liver	57.0	0.15	8.7			
		Total body	Totals for Chain		73.0			
		Lung (insol.)			27.0			
		Bone			360.0			
		Kidney			72.0			
		Liver			68.0			
$_{95}Am^{242}$	0.67	Total body	0.13	1.0	0.13	0.089	0.13	0.073
		Lung (insol.)	0.089	1.0	0.089			
16%		Bone	0.23	1.0	0.23			
		Kidney	0.080	1.0	0.080			
		Liver	0.089	1.0	0.089			
Pu^{242}	1.4×10^8	Total body	51.0	8.3×10^{-5}	0.0042	0.49	0.50	0.49
		Lung (insol.)	51.0	2.6×10^{-6}	10^{-4}			
		Bone	253.0	8.4×10^{-5}	0.021			
		Kidney	51.0	7.6×10^{-5}	0.0038			
		Liver	51.0	7.5×10^{-5}	0.0038			
		Total body	Totals for Chain		0.13			
		Lung (insol.)			0.088			
		Bone			0.25			
		Kidney			0.084			
		Liver			0.092			

Table 5a—continued

Radionuclide	Half-life (T_r in days)	Effective energy for organs of reference				ΣE(RBE) (E in MeV) for GI tract		
		Organs of Reference	ΣE(RBE)n (E in MeV)	F	ΣEF(RBE)n (E in MeV)	S	SI	LI
$_{95}Am^{243}$	0.67	Total body	0.24	1.0	0.24	0.24	0.24	0.23
		Lung (insol.)	0.24	1.0	0.24			
		Bone	1.1	1.0	1.1			
		Kidney	0.24	1.0	0.24			
84%		Liver	0.24	1.0	0.24			
Cm^{242}	162.5	Total body	63.0	0.99	63.0	0.63	0.63	0.63
		Lung (insol.)	63.0	0.43	27.0			
		Bone	315.0	1.0	314.0			
		Kidney	63.0	0.99	63.0			
		Liver	63.0	0.95	60.0			
Pu^{238}	3.2×10^4	Total body	57.0	0.30	17.0	0.57	0.57	0.57
		Lung (insol.)	57.0	0.0049	0.28			
		Bone	283.0	0.30	86.0			
		Kidney	57.0	0.27	16.0			
		Liver	57.0	0.26	15.0			
		Total body	Totals for Chain		80.0			
		Lung (insol.)			27.0			
		Bone			400.0			
		Kidney			78.0			
		Liver			75.0			
Am^{244}	0.018	Total body	0.52	1.0	0.52	0.52	0.52	0.52
		Lung (insol.)	0.52	1.0	0.52			
		Bone	2.6	1.0	2.6			
		Kidney	0.52	1.0	0.52			
		Liver	0.52	1.0	0.52			
Cm^{244}	6.4×10^3	Total body	60.0	0.72	43.0	0.59	0.59	0.59
		Lung (insol.)	60.0	0.018	1.1			
		Bone	299.0	0.81	243.0			
		Kidney	60.0	0.72	43.0			
		Liver	60.0	0.32	19.0			
Pu^{240}	2.4×10^6	Total body	53.0	0.0024	0.13	0.52	0.52	0.52
		Lung (insol.)	53.0	2.8×10^{-6}	10^{-4}			
		Bone	266.0	2.7×10^{-3}	0.71			
		Kidney	53.0	2.3×10^{-3}	0.12			
		Liver	53.0	1.2×10^{-3}	0.063			
		Total body	Totals for Chain		44.0			
		Lung (insol.)			1.6			
		Bone			250.0			
		Kidney			44.0			
		Liver			20.0			

Table 5a—*continued*

Radionuclide	Half-life (T_r in days)	Effective energy for organs of reference				ΣE(RBE) (E in MeV) for GI tract		
		Organs of Reference	ΣE(RBE)n (E in MeV)	F	ΣEF(RBE)n (E in MeV)	S	SI	LI
$_{96}Cm^{247}$	3.3×10^{10}	Total body	55.0	1.0	55.0	0.53	0.53	0.53
		Lung (insol.)	55.0	1.0	55.0			
		Bone	273.0	1.0	273.0			
		Kidney	55.0	1.0	55.0			
		Liver	55.0	1.0	55.0			
Pu^{243}	0.21	Total body	0.19	1.0	0.19	0.18	0.19	0.18
		Lung (insol.)	0.18	1.0	0.18			
		Bone	0.88	1.0	0.88			
		Kidney	0.18	1.0	0.18			
		Liver	0.18	1.0	0.18			
Am^{243}	2.9×10^{6}	Total body	54.0	1.9×10^{-3}	0.10	0.55	0.57	0.55
		Lung (insol.)	54.0	4.1×10^{-5}	0.0022			
		Bone	272.0	2.1×10^{-3}	0.57			
		Kidney	54.0	2.0×10^{-3}	0.11			
		Liver	54.0	1.1×10^{-3}	0.059			
		Total body	Totals for Chain		55.0			
		Lung (insol.)			55.0			
		Bone			270.0			
		Kidney			55.0			
		Liver			55.0			
$_{96}Cm^{249}$	0.044	Total body	0.28	1.0	0.28	0.28	0.28	0.28
		Lung (insol.)	0.28	1.0	0.28			
		Bone	1.4	1.0	1.4			
Bk^{249}	314.0	Total body	0.032	1.0	0.032	0.032	0.032	0.032
		Lung (insol.)	0.032	0.28	0.0088			
		Bone	0.16	1.0	0.16			
Cf^{249}	1.3×10^{5}	Total body	60.0	0.082	4.9	0.68	0.80	0.63
		Lung (insol.)	60.0	2.5×10^{-4}	0.015			
		Bone	301.0	0.083	25.0			
Cm^{245}	4.4×10^{6}	Total body	56.0	10^{-4}	0.0056	0.57	0.61	0.56
		Lung (insol.)	56.0	6.9×10^{-9}	3.9×10^{-7}			
		Bone	277.0	1.1×10^{-4}	0.032			
		Total body	Totals for Chain		5.2			
		Lung (insol.)			0.31			
		Bone			27.0			
$_{97}Bk^{250}$	0.13	Total body	0.83	1.0	0.83	0.52	0.83	0.41
		Lung (insol.)	0.52	1.0	0.52			
		Bone	1.5	1.0	1.5			
Cf^{250}	4.0×10^{3}	Total body	62.0	0.91	56.0	0.61	0.61	0.61
		Lung (insol.)	62.0	0.029	1.8			
		Bone	311.0	0.91	284.0			

Table 5a—*continued*

Radionuclide	Half-life (T_r, in days)	Effective energy for organs of reference				ΣE(RBE) (E in MeV) for GI tract		
		Organs of Reference	ΣE(RBE)n (E in MeV)	F	ΣEF(RBE)n (E in MeV)	S	SI	LI
Cm^{246}	2.0×10^6	Total body	56.0	0.0035	0.19	0.54	0.54	0.54
		Lung (insol.)	56.0	1.8×10^{-6}	10^{-4}			
		Bone	278.0	0.0040	1.1			
		Total body	Totals for Chain		57.0			
		Lung (insol.)			2.3			
		Bone			290.0			
$_{98}Cf^{253}$	18.0	Total body	0.081	1.0	0.081	0.081	0.081	0.081
		Lung (insol.)	0.081	1.0	0.081			
		Bone	0.40	1.0	0.40			
Es^{253}	20.0	Total body	68.0	1.0	68.0	0.67	0.67	0.67
		Lung (insol.)	68.0	0.86	59.0			
		Bone	342.0	1.0	342.0			
Bk^{249}	314.0	Total body	0.032	1.0	0.032	0.032	0.032	0.032
		Lung (insol.)	0.032	0.24	0.0075			
		Bone	0.16	1.0	0.16			
Cf^{249}	1.3×10^5	Total body	60.0	0.081	4.9	0.68	0.80	0.63
		Lung (insol.)	60.0	2.2×10^{-4}	0.013			
		Bone	301.0	0.083	25.0			
Cm^{245}	4.4×10^6	Total body	56.0	10^{-4}	0.056	0.57	0.61	0.56
		Lung (insol.)	56.0	5.9×10^{-9}	3.3×10^{-7}			
		Bone	277.0	1.1×10^{-4}	0.032			
		Total body	Totals for Chain		73.0			
		Lung (insol.)			59.0			
		Bone			370.0			
$_{99}Es^{253}$	20.0	Total body	68.0	1.0	68.0	0.67	0.67	0.67
		Lung (insol.)	68.0	1.0	68.0			
		Bone	342.0	1.0	342.0			
Bk^{249}	314.0	Total body	0.032	1.0	0.032	0.032	0.032	0.032
		Lung (insol.)	0.032	0.28	0.0088			
		Bone	0.16	1.0	0.16			
Cf^{249}	1.3×10^5	Total body	60.0	0.082	4.9	0.68	0.80	0.63
		Lung (insol.)	60.0	2.5×10^{-4}	0.015			
		Bone	301.0	0.083	25.0			
Cm^{245}	4.4×10^6	Total body	56.0	10^{-4}	0.0056	0.57	0.61	0.56
		Lung (insol.)	56.0	6.9×10^{-9}	3.9×10^{-7}			
		Bone	277.0	1.1×10^{-4}	0.032			
		Total body	Totals for Chain		73.0			
		Lung (insol.)			68.0			
		Bone			370.0			

Table 5a—*continued*

Radionuclide	Half-life (T_r in days)	Effective energy for organs of reference				ΣE(RBE) (E in MeV) for GI tract		
		Organs of Reference	ΣE(RBE)n (E in MeV)	F	ΣEF(RBE)n (E in MeV)	S	SI	LI
$_{99}Es^{254}$	1.6	Total body	0.45	1.0	0.45	0.34	0.45	0.30
		Lung (insol.)	0.34	1.0	0.34			
		Bone	1.3	1.0	1.3			
Fm^{254}	0.14	Total body	74.0	1.0	74.0	0.73	0.73	0.73
		Lung (insol.)	74.0	1.0	74.0			
		Bone	371.0	1.0	371.0			
Cf^{250}	4.0×10^3	Total body	62.0	0.91	56.0	0.61	0.61	0.61
		Lung (insol.)	62.0	0.029	1.8			
		Bone	311.0	0.91	284.0			
Cm^{246}	2.0×10^6	Total body	56.0	0.0035	0.19	0.54	0.54	0.54
		Lung (insol.)	56.0	1.8×10^{-6}	10^{-4}			
		Bone	278.0	0.0040	1.1			
		Total body	Totals for Chain		130.0			
		Lung (insol.)			76.0			
		Bone			660.0			
$_{99}Es^{254}$	480.0	Total body	66.0	1.0	66.0	0.66	0.68	0.65
		Lung (insol.)	66.0	1.0	66.0			
		Bone	332.0	1.0	332.0			
Bk^{250}	0.13	Total body	0.82	1.0	0.82	0.52	0.83	0.41
		Lung (insol.)	0.52	1.0	0.52			
		Bone	1.5	1.0	1.5			
Cf^{250}	4.0×10^3	Total body	62.0	0.90	56.0	0.61	0.61	0.61
		Lung (insol.)	62.0	0.029	1.8			
		Bone	310.0	0.91	282.0			
Cm^{246}	2.0×10^6	Total body	56.0	0.0033	0.18	0.54	0.54	0.54
		Lung (insol.)	56.0	1.8×10^{-6}	10^{-4}			
		Bone	278.0	0.0038	1.1			
		Total body	Totals for Chain		120.0			
		Lung (insol.)			69.0			
		Bone			620.0			
$_{99}Es^{255}$	30.0	Total body	0.12	1.0	0.12	0.12	0.12	0.12
		Lung (insol.)	0.12	1.0	0.12			
		Bone	0.58	1.0	0.58			
Fm^{255}	0.90	Total body	73.0	1.0	73.0	0.71	0.71	0.71
		Lung (insol.)	73.0	0.99	72.0			
		Bone	365.0	1.0	365.0			
Cf^{251}	2.9×10^5	Total body	59.0	0.038	2.3	0.61	0.65	0.59
		Lung (insol.)	59.0	4.1×10^{-4}	0.024			
		Bone	295.0	0.039	11.0			

Table 5a—*continued*

Radionuclide	Half-life (T_r in days)	Effective energy for organs of reference				ΣE(RBE) (E in MeV) for GI tract		
		Organs of Reference	ΣE(RBE)n (E in MeV)	F	ΣEF(RBE)n (E in MeV)	S	SI	LI
		Total body	Totals for Chain		75.0			
		Lung (insol.)			73.0			
		Bone			380.0			
$_{100}Fm^{254}$	0.14	Total body	74.0	1.0	74.0	0.73	0.73	0.73
99.9448 %		Lung (insol.)	74.0	1.0	74.0			
		Bone	371.0	1.0	371.0			
Cf^{250}	4.0×10^3	Total body	62.0	0.91	56.0	0.61	0.61	0.61
		Lung (insol.)	62.0	0.029	1.8			
		Bone	311.0	0.91	284.0			
Cm^{246}	2.0×10^6	Total body	56.0	0.0035	0.19	0.54	0.54	0.54
		Lung (insol.)	56.0	1.8×10^{-6}	10^{-4}			
		Bone	278.0	0.0040	1.1			
		Total body	Totals for Chain		130.0			
		Lung (insol.)			76.0			
		Bone			660.0			
$_{100}Fm^{255}$	0.90	Total body	73.0	1.0	73.0	0.71	0.71	0.71
		Lung (insol.)	73.0	1.0	73.0			
		Bone	365.0	1.0	365.0			
Cf^{251}	2.9×10^5	Total body	59.0	0.039	2.3	0.61	0.65	0.59
		Lung (insol.)	59.0	4.1×10^{-4}	0.024			
		Bone	295.0	0.039	12.0			
		Total body	Totals for Chain		75.0			
		Lung (insol.)			73.0			
		Bone			380.0			

1962 SUPPLEMENT TO ICRP PUBLICATION 2, TABLE 12
Biological and Related Physical Constants

Gen.* ref. / Z	Element and radionuclides	Average daily ingestion I (g/day)	Organ of reference mass (g) effective radius (cm)	Average concentration, C (g/g wet tissues)	Half-life (days)			Fraction from GI tract to blood f_1	Fraction in organ of reference of that in total body f_2		Fraction from blood to organ of reference f_2'	Fraction reaching organ of reference	
					Physical T_r	Biological T_b	Effective T		Element	Radionuclide		By ingestion f_w	By inhalation f_a
			Ch-1			eq. 44, 45	eq. 49			eq.41,42		eq. 47	eq. 46
92	U	2×10^{-6} (Da-1)	Total body 7×10^{4} g 30 cm	3×10^{-10}		100.0 (Ber-1 Ber-3)		$<10^{-2}$	1.0 (D)		1.0 (D)	10^{-2}	0.26
	U^{240}				0.588		0.585			1.0 (D)			
	U		Bone 7×10^{3} g 5 cm	10^{-9} (Ly-1)		300.0 (Ber-1 Ber-3)			0.85 (Vo-1)		0.11 (Ber-1 Ber-3)	1.1×10^{-3}	0.028
	U^{240}				0.588		0.587			0.85 (Vo-1)			
	U		Kidney 300 g 7 cm	2×10^{-8} (Vo-1)		15.0 (Vo-1 Sx-1 McL-1)			0.065 (Vo-1)		0.11 (Vo-1 Sx-1 McL-1)	1.1×10^{-3}	0.028
	U^{240}				0.588		0.566			0.065 (Vo-1)			
94	Pu		Total body 7×10^{4} g 30 cm			6.5×10^{4}		3×10^{-5} (Ln-5 Bal-1 Bs-4 Kt-6)	1.0 (D)		1.0 (D)	3×10^{-5}	0.25
	Pu^{243}				0.208		0.208			1.0 (D)			
	Pu^{244}				2.8×10^{10}		6.5×10^{4}			1.0 (D)			

94	Pu		Bone 7×10^{3} g 5 cm			7.3×10^{4} (Ln-5 Ln-12)			0.9 (Ln-5 Kt-2)		0.8 (Ln-5 Ha-93)	2.4×10^{-5} (Ph-1 Ph-2 Kt-6)	0.2
	Pu^{243} Pu^{244}				0.208 2.8×10^{10}		0.208 7.3×10^{4}			0.8 0.90			
	Pu		Liver 1.7×10^{3} g 10 cm			3×10^{4}			0.07 (Ln-4 Ha-26)		0.15 (Ln-4 Ha-26)	4.5×10^{-6}	0.038
	Pu^{243} Pu^{244}				0.208 2.8×10^{10}		0.208 3×10^{4}			0.15 0.069			
	Pu		Kidneys 300 g 7 cm			3.2×10^{4}			0.01 (Ln-4 Ha-26)		0.02 (Ln-4 Ha-26)	6×10^{-7}	5×10^{-3}
	Pu^{243} Pu^{244}				0.208 2.8×10^{10}		0.208 3.2×10^{4}			0.02 0.0098			
95	Am		Total body 7×10^{4} g 30 cm			2×10^{4}		$<10^{-4}$ (Ha-13 Ha-62 com- pared to 4f rare earths)	1.0 (D)		1.0 (D)	10^{-4}	0.25
	Am^{242m} Am^{243} Am^{244}				5.6×10^{4} 0.667 0.0181		1.5×10^{4} 0.667 0.0181			1.0 (D) 1.0 (D) 1.0 (D)			
	Am		Bone 7×10^{3} g 5 cm			7.3×10^{4} (com- pared to Pu)			0.9 (Ha-1 Ha-13)		0.25 (Ha-13)	2.5×10^{-5}	0.063
	Am^{242m}				5.6×10^{4}		3.2×10^{4}			0.54			

* Reference equations unless otherwise indicated.

Table 12—continued

Gen.* ref. / Z	Element and radionuclides	Average daily ingestion I (g/day)	Organ of reference mass (g) effective radius (cm)	Average concentration, C (g/g wet tissues)	Half-life (days) Physical T_r	Half-life (days) Biological T_b	Half-life (days) Effective T	Fraction from GI tract to blood f_1	Fraction in organ of reference of that in total body f_2 Element	Fraction in organ of reference of that in total body f_2 Radionuclide	Fraction from blood to organ of reference f_2	Fraction reaching organ of reference By ingestion f_w	Fraction reaching organ of reference By inhalation f_a
			Ch-1			eq. 44, 45	eq. 49			eq.41,42		eq. 47	eq. 46
	Am^{242}				0.667		0.667			0.25			
	Am^{244}				0.0181		0.018			0.25			
	Am		Kidney 300 g 7 cm			2.7×10^{4}			0.04 (Ha-13)		0.03 (Ha-13)	3×10^{-6}	7.5×10^{-3}
	Am^{242m}				5.6×10^{4}		1.8×10^{4}			0.037			
	Am^{242}				0.667		0.667			0.03			
	Am^{244}				0.0181		0.018			0.03			
	Am		Liver 1.7×10^{3} g 10 cm			3.48×10^{3}			0.06 (Ha-13)		0.35 (Ha-13)	3.5×10^{-5}	0.088
	Am^{242m}				5.6×10^{4}		3.3×10^{3}			0.078			
	Am^{242}				0.677		0.667			0.35			
	Am^{244}				0.0181		0.018			0.35			
96	Cm		Total body 7×10^{4} g 30 cm			2.4×10^{4}		$<10^{-4}$ (Ha-12 compared to 4f rare earths)	1.0 (D)		1.0 (D)	10^{-4}	0.25
	Cm^{247}				3.3×10^{10}		2.4×10^{4}			1.0 (D)			
	Cm^{248}				1.7×10^{8}		2.4×10^{4}			1.0 (D)			

	Cm^{249}				0.044		0.044			1.0 (D)			
	Cm		Bone 7×10^3 g 5 cm			7.3×10^4 (compared to Pu)			0.9 (Ha-12)		0.3 (Ha-12)	3×10^{-5}	0.075
	Cm^{247}				3.3×10^{10}		7.3×10^4			0.91			
	Cm^{248}				1.7×10^8		7.3×10^4			0.91			
	Cm^{249}				0.044		0.044			0.3			
	Cm		Kidneys 300 g 7 cm			2.4×10^4			0.02 (Ha-12)		0.02 (Ha-12)	2×10^{-6}	5×10^{-3}
	Cm^{247}				3.3×10^{10}		2.4×10^4			0.02			
	Cm^{248}				1.7×10^8		2.4×10^4			0.02			
	Cm		Liver 1.7×10^3 g 10 cm			3.0×10^3			0.05 (Ha-12)		0.4 (Ha-12)	4×10^{-5}	0.1
	Cm^{247}				3.3×10^{10}		3.0×10^3			0.05			
	Cm^{248}				1.7×10^8		3.0×10^3			0.05			
97	Bk		Total body 7×10^4 g 30 cm			6.5×10^4		3×10^{-5} (compared to Pu)	1.0 (D)		1.0 (D)	3×10^{-5}	0.25
	Bk^{250}				0.134		0.134			1.0 (D)			
	Bk		Bone 7×10^3 g 5 cm			7.3×10^4 (compared to Pu)			0.9 (compared to Pu)		0.8 (compared to Pu)	2.4×10^{-5}	0.2
	Bk^{250}				0.134		0.134			0.8			
98	Cf		Total body 7×10^4 g			6.5×10^4		3×10^{-5}	1.0 (D)		1.0 (D)	3×10^{-5}	0.25

* Reference equations unless otherwise indicated.

Table 12—continued

Gen.* ref. / Z	Element and radionuclides	Average daily ingestion I (g/day)	Organ of reference mass (g) effective radius (cm)	Average concentration, C (g/g wet tissues)	Half-life (days) Physical T_r	Half-life (days) Biological T_b	Half-life (days) Effective T	Fraction from GI tract to blood f_1	Fraction in organ of reference of that in total body f_2 Element	Fraction in organ of reference of that in total body f_2 Radionuclide	Fraction from blood to organ of reference f_2'	Fraction reaching organ of reference By ingestion f_w	Fraction reaching organ of reference By inhalation f_a
			Ch-1			eq. 44, 45	eq. 49			eq.41,42		eq. 47	eq. 46
			30 cm					(compared to Pu)					
	Cf^{251}				2.9×10^5		5.3×10^4			1.0 (D)			
	Cf^{253}				18.0		18.0			1.0 (D)			
	Cf^{254}				56.0		56.0			1.0 (D)			
	Cf		Bone 7×10^3 g 5 cm			7.3×10^4 (compared to Pu)			0.9 (compared to Pu)		0.8 (compared to Pu)	2.4×10^{-5}	0.2
	Cf^{251}				2.9×10^5		5.8×10^4			0.88			
	Cf^{253}				18.0		18.0			0.80			
	Cf^{254}				56.0		56.0			0.80			
99	Es		Total body 7×10^4 g 30 cm			6.5×10^4 (compared to Pu)		3×10^{-5} (compared to Pu)	1.0 (D)		1.0 (D)	3×10^{-5}	0.25
	Es^{253}				20.0		20.0			1.0 (D)			
	Es^{254m}				1.60		1.60			1.0 (D)			
	Es^{254}				480.0		476.0			1.0 (D)			
	Es^{255}				30.0		30.0			1.0 (D)			
	Es		Bone 7×10^3 g 5 cm			7.3×10^4 (compared to Pu)			0.9 (compared to Pu)		0.8 (compared to Pu)	2.4×10^{-5}	0.20

	Es^{253}				20.0		20.0			0.8			
	Es^{254m}				1.60		1.60			0.8			
	Es^{254}				480.0		477.0			0.8			
	Es^{255}				30.0		30.0			0.8			
100	Fm		Total body 7×10^4 g 30 cm			6.5×10^4		3×10^{-5} (compared to Pu)	1.0 (D)		1.0 (D)	3×10^{-5}	0.25
	Fm^{254}				0.135		0.135			1.0 (D)			
	Fm^{255}				0.896		0.896			1.0 (D)			
	Fm^{256}				0.111		0.111			1.0 (D)			
	Fm		Bone 7×10^3 g 5 cm			7.3×10^4 (compared to Pu)			0.9 (compared to Pu)		0.8 (compared to Pu)	2.4×10^{-5}	0.20
	Fm^{254}				0.135		0.135			0.8			
	Fm^{255}				0.896		0.896			0.8			
	Fm^{256}				0.111		0.111			0.8			

* Reference equations unless otherwise indicated.

Errata

(This list includes corrections based on the first printing, many of which were corrected in later printings. This list does not include new recommendations which are presented in the main text of the 1962 Supplement.)

Page 10

Line 9. " 1.7×10^{8} dis./sec from U^{235} " should read " 1.7×10^{9} dis./sec from U^{235} ".

Page 17

Equation (9). After the equals sign, in the expression enclosed in square brackets, a subscript " j " is missing from " λ^r " which should appear as " λ_j^r ".

Page 18

Equation (10). " $\sum_{j=0}^{i}$ " should read " $\sum_{h=0}^{i}$ ".

Page 36

Equation (59). The exponential should read " $e^{-\lambda^r(t-1)}$ ".

Equation (60). Insert " d_τ " before the second equals sign. The last exponential should read " $e^{-\lambda^r(\mu-1)}$ ".

Equation (61). The exponential should read " $e^{-\lambda^r(\mu-1)}$ ".

Equation (62). The exponential should read " $e^{-\lambda^r(\mu-1)}$ ".

Page 44

Opposite $_{24}Cr^{51}$ (sol), columns 4 and 6, respectively—

Total body: " 0.6 " and " 0.2 " should read " 6 " and " 2 ".

Lung: " 1 " and " 0.4 " should read " 10 " and " 4 ".

Prostate: " 2 " and " 0.5 ", should read " 20 " and " 5 ".

Thyroid: " 3 " and " 1 " should read " 30 " and " 10 ".

Kidney: " 6 " and " 2 " should read " 60 " and " 20 ".

Page 48

Opposite $_{33}As^{74}$ (sol), Kidney, column 5: The entry is not clear; it should read " 2×10^{-6} ".

Page 55

Opposite $_{45}Rh^{105}$ (sol), Bone, columns 4 and 6, respectively: " 8×10^{-3} " and " 3×10^{-3} " should read " 0.8 " and " 0.3 ".

Page 58

Opposite $_{51}Sb^{125}$ (sol), Liver, column 3: " 3×10^{-3} " should read " 3×10^{3} ".

Page 59

Opposite $_{52}Te^{125m}$ (sol), Testis, column 4: " 6×10^{-7} " should read " 6×10^{-3} ".

Page 64

Opposite $_{59}Pr^{142}$ (sol), Liver, column 5: The sign in the power of ten is missing; it should read " 4×10^{-6} ".

Page 67

Opposite $_{64}Gd^{153}$ (sol), GI(LLI), column 5: " 10^{-3} " should read " 10^{-6} ".

Page 69

Opposite $_{70}Yb^{175}$ (sol), GI(LLI), column 5: " 6×10^{-7} " should read " 7×10^{-7} ".

Page 87

In the third entry under " Limitations ": " if the α-emitting radionuclide Ac^{227} is not present " should read " if the β-emitting radionuclide Ac^{227} is not present ".

Page 88

Opposite $_{6}C^{14}(CO_2)$, Bone, column 4: " 2.7 " should read " 0.27 ".

Page 147

Opposite Ileum, in column Cd: " < 26.0 " should read " < 0.26 ".

Page 148

Opposite Aorta, in column Cs: " < 1.4 " should read " < 0.02 ".

Opposite Blood, in column Cl: " 320(R) " should read " 2800(S) ".

Opposite Blood, in column Fe: " 0.5(S) " should read " 450(E) ".

Opposite Blood, in column I: " 390(S) " should read " 0.07(S) ".

Opposite Blood, in column K: " 11 " should read " 1800(S) ".

Page 149

Opposite Cecum, in column Mn: " 0.93 " should read " 0.38 ".

Page 150

Opposite Blood, in column Zn: " 9.3(S) " should read " 8.3(S) ".

Page 159

Opposite $_{15}P$, Bone, column 12: " 0.2 (Ph–4) " should read " 0.5 ".

Page 160

Opposite $_{16}S$, Testes, column 10: " 9×10^{-6} " should read " 9×10^{-3} ".

Page 165

Opposite $_{25}Mn^{52}$, Total body, column 8: " 2.8 " should read " 4.2 ".

Opposite $_{25}Mn^{54}$, Total body, column 8: " 5.6 " should read " 16.2 ".

Page 167

For Co, the following five lines of data concerning the kidney should be inserted after the data for pancreas:

Columns												
2	3	4	5	6	7	8	9	10	11	12	13	14
Co		Kidneys 300 g 7 cm	2×10^{-7}		9.5			0.15		2×10^{-3}	6×10^{-4}	8×10^{-4}
Co^{57}				270.0		9.2			2×10^{-3}			
Co^{58m}				0.38		0.37			2×10^{-3}			
Co^{58}				72.0		8.4			2×10^{-3}			
Co^{60}				1.9×10^{3}		9.5			2×10^{-3}			

Page 168

Opposite $_{28}Ni^{63}$, Bone, column 8: " 492 " should read " 779 ".

Page 175

Opposite $_{37}Rb^{87}$, Pancreas, column 11: The power of ten is missing; it should read " 4×10^{-3} ".

Page 176

In column 2, fourth item down: " S^{89} " should read " Sr^{89} ".

Page 184

Opposite $_{47}Ag$, Total body: Entries in columns 3 and 5 should be interchanged.

Page 187

In column 2, fourth item down: " in^{115m} " should read " In^{115m} ".

Page 192

Opposite $_{52}Te$, Testes, column 5: " 3×10^{-4} " should read " 4.2×10^{-5} ".

Page 194

Opposite $_{53}I^{129}$, Spleen, column 11: " 0.0025 " should read " 2.5×10^{-4} ".

Page 207

Opposite $_{68}Er$, Kidneys, column 13: The power of ten is not clear; it should read " 2×10^{-6} ".

Page 217

Opposite $_{82}Pb$, Bone, column 5: " $< 10^{-6}$ " should read " 6.6×10^{-6} ".

Page 221

Opposite $_{88}Ra^{226}$, Bone: Entries in last two columns should be interchanged.

Opposite $_{88}Ra^{228}$, Bone: Entries in last two columns should be interchanged.

Page 225

In column 2, second item down: " Pa^{232} " should read " Pa^{233} ".

Opposite $_{92}U^{230}$, Total body, column 8: " 14.7 " should read " 17.2 ".

Page 226

Opposite $_{92}U$, Bone, column 12: " 0.33 " should read " 0.11 ".

Opposite $_{92}U$, Bone, column 13: " 3.3×10^{-5} " should read " 1.1×10^{-5} ".

Opposite $_{92}U$, Bone, column 14: " 0.083 " should read " 0.028 ".

Opposite $_{92}U_{230}$, Bone, column 11: " 0.44 " should read " 0.85 ".

Opposite $_{93}Np$, Bone, column 13: " 5.4×10^{-5} " should read " 4.5×10^{-5} ".

Page 230

Opposite $_{97}Bk$, Total body, column 9: The power of ten is not clear; it should read " 3×10^{-5} ".

Page 233

Seventh item from the bottom of the left-hand column: " ϵ " should read " ε ".

6. 1962 ADDENDUM

TO

REPORT OF COMMITTEE III

ON PROTECTION AGAINST X-RAYS UP TO ENERGIES OF 3 MeV AND BETA- AND GAMMA-RAYS FROM SEALED SOURCES

(ICRP PUBLICATION 3)

The 1960 Report of Committee III was subjected to an extensive review at a meeting in Stockholm in May 1962. As a result of this review, it has been decided to publish a revised and extended Report as soon as possible. In the meantime, this Addendum to the 1960 report is issued.

Page 4 **Industrial protective source housing**
It may not always be practicable to use the *industrial protective source housing* for a number of applications such as site radiography. If housings providing less shielding are used, the weekly work-load or degree of occupancy, or both, may need to be reduced in order to ensure that the doses received are within the specified limits. Industrial protective source housings should be marked with the activities of the various isotopes for which they are intended to be used. If the housing does not conform to the definition of industrial protective source housing, it should be marked with the nature and activity of the contents and the exposure rate at 5 cm from the surface.

Page 8 Para. 48. The following sentence to be added:
" The exposure rate used in fluoroscopy should be as low as is consistent with the fluoroscopic requirements and shall not normally exceed 10 röntgens per minute (measured in air) at the position where the beam normally enters the patient."

Page 8 Para. 50. The following sentence to be added:
" In the case of image intensifier equipment which requires the operator to be positioned in close proximity to the X-ray tube and where the protective apron referred to in para. 49 is not provided, an additional protective shield may be necessary."

Page 21 Table 1. Wards and patients' rooms should be transferred from Partial Occupancy to Full Occupancy.

Page 32 Figure 6. Replace the final sentence of the footnote by the following:
" Constant potentials may require up to 25 per cent thicker barriers than the pulsating potentials given above."

Page 36 Figure 10. The following sentence should be added to the footnote:
" Constant potentials may require up to 15 per cent thicker barriers than the pulsating potentials given above."

Page 38 Figure 12. The radium curve is in error for small transmissions. For 10 cm lead the transmission should be 0.005, and for 20 cm lead the transmission should be 0.00003.

Page 44 Figure 18. In the footnote, for a field size of " 20 cm " read " 30 cm ".

Page 46 Figure 20. The ordinate should be marked " Energy of electrons, MeV ".